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Taxonomic Transformations of Visual Media Selections into Display Specification

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This research examined relationships between characteristics of visual stimuli and learning as a first step in developing decision-support systems to help estimate visual fidelity requirements for device-based training. On the basis of reviews of psychophysical and other literature, the authors concluded that little is known about the relationships between characteristics of visual stimuli and learning. An experimental decision-support system was nevertheless developed, with critical "gaps" in essential data as noted in this report.

Information in this report may be helpful in estimating visual display parameters. Examining the quality of the estimates will require validation research that, because of the time and cost constraints in training-device development, is unlikely to be feasible.

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FOREWORD

Often diverse disciplines, such as training and design, have such different concepts and terminology that it is difficult to convey the ideas from one discipline to another. By posing questions in the terms and methods of one group and then translating to the language of the other group, it is possible to convey information in a useable and understandable format. We used this approach by employing a query structure for users of visual systems, e.g., Instructional Technologists, and translated their answers into engineering system descriptions. In doing so, we were able to structure a taxonomy that conveys to engineers sufficient design parameters to allow them to develop a system that meets the functional requirements of the task. The result is a mechanism that allows users to state exactly what they want developed and allows designers the flexibility to meet those needs with innovation and cost effectiveness.

This project follows an initial investigation conducted under the auspices of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) with the guidance and inspiration of ARI's Dee H. Andrews and J. Peter Kincaid. That initial work was to enhance the technical understanding of visual systems for nontechnical users. The result of that project (Gilson, R. D., and Myler, H. R. "Visual Display Taxonomy." Final Technical Report for the Army Research Institute and the Defense Training and Performance Data Center, April 1988) was a 40-slide display describing basic visual display concepts for nontechnical users. That project informed users about terminology and concepts, but it did not provide guidance for system selection. The current project substantially advances that first effort by providing the guidance for system selection.

The intent behind this work is to provide a knowledgeable user-driven selection process rather than a seller-driven one. Clearly, users are in the best position to define their needs, but often they need help in translating those requirements into system specifications. System specifications are typically defined in terms in which users have no expertise. This taxonomic structure is therefore an aid in both the design process and the procurement process.

The structure complements well-established principles of task analysis by the user. In constructing the taxonomy there is no way of knowing the specifics of a particular application. The ultimate choice must be made by the user with specific knowledge of their needs using well-documented techniques such as Instructional System Design.

This project is, to our knowledge, the first to translate user imaging needs into design descriptions. The paper taxonomy (and much more easily, the experimental electronic taxonomy) allows for user reentry into the structure for refinements to elicit the best possible system description. This reentry option was the primary impetus for placing the taxonomy in an expert system program (Level V by Information Builders, Inc.) as a concept demonstration. The expert system illustrated two points. First, it could hide the structural complexity that might otherwise intimidate a potential user. Second, the expert system showed the ease of interacting electronically with the taxonomy compared to the intensive referencing required with paper form.

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I deeply appreciate the work contributed by each member of the research team from the Psychology and Computer Engineering Departments at the University of Central Florida. Coprincipal investigator Dr. Harley Myler and team members Jada Brooks, Steve Gibbons, Amy Morris, and Hoi Yoo put forth extraordinary efforts and exhibited great perseverance in completing this project.

I also would like to express my great appreciation to the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) staff members for their technical advice and guidance during this project. In particular, Drs. John Boldovici and Michael Singer provided essential thought and counsel throughout the project, but most importantly in key focus at the beginning.

Finally, I would like to thank the contract administrators Ms. Betsy Gray at UCF/DSR and Mr. Ray Fegal at ARI (Orlando Field Office) for their fine work in keeping the project on track. I believe we kept contract changes to a necessary minimum.

TAXONOMIC TRANSFORMATIONS OF VISUAL MEDIA SELECTIONS INTO DISPLAY SPECIFICATIONS

EXECUTIVE SUMMARY

Procedure:

The primary research goal was a method for facilitating the design of visual display systems based on human visual capabilities and training needs. The first step was a directed review for data bases, reviews, and studies presently available in the literature that relate categories of visual display characteristics, human visual functions, and/or visual training requirements. No existing taxonomies, categorization schemes, or data bases were found that could meet the specific objectives of this project. Thus, the literature review shifted to collecting relevant but diverse data and the development of a new taxonomic structure. Included in the assembled results were general training guidelines, sensory and perceptual correlates of image specifications, their psychophysical functions, and display design characteristics. Information gaps in relevant areas were identified.

A taxonomic categorization scheme was based on this assembled data. Categories were determined based on functional capabilities that define a visual system to engineers, e.g., update rates, pixel densities, refresh rates, and luminance capabilities. The chosen approach was to create a taxonomy based on a user query system and a tree structure of outcomes based on those choices. The philosophy is that only the user is knowledgeable about the specific task. With a structured flow of questions and answers the user would be guided into the best design given that specific task. As a key ingredient of the taxonomic scheme, the engineering functions and terminology were translated into nontechnical questions and explanations that are more readily understood by nonengineers.

The experimental portion of the project was initiated to find an appropriate presentation format for the taxonomy. An expert system illustrated an easy to use presentation format and provide an effective shell to hold the collected information.

Findings:

The directed review of existing literature indicated that this is the first taxonomy of its kind relating imaging requirements with capacities of the human visual system to obtain design descriptions. No specific rules were found for visual presentations for training. Some recommendations were found for specific visual functions: critical flicker fusion, effects of ambient illumination, or luminance relationship to contrast. But these recommendations were for selected areas and did not provide information across functions related to the imaging system as a whole.

The basic idea in the use of this taxonomy is to specify an image, relate the image to visual functions, and translate the image specification into generic visual system characteristics separate from current technology limitations. The final characteristics are broad enough to allow design engineers innovative flexibility to tailor hardware configurations to meet both application and procurement requirements. The taxonomy also will help engineers to identify more clearly the conventional sources available to satisfy imaging requirements while allowing the inclusion of new technologies in appropriate applications. By specifying the imaging requirements and not the hardware, the taxonomy does not date itself.

It was determined through an experimental software application that the most appropriate media presentation format for the taxonomy should be an interactive expert system. The elaborate branches of the tree structures provide queries and information for the user to access many different areas of the taxonomy. The frequent accessing of information necessary to use the taxonomy is cumbersome using paper copy methods, yet it is easy in an electronic format. Thus, the reason for experimenting with an expert system as concept demonstration is obvious. An electronic presentation can free the user from manually searching through documentation in the attempt to locate information. It allows rapid access to the relevant material at the approriate times.

Gaps in knowledge were found and documented in the area of scene complexity, level of resolution required, and in the recommendation for field of view (FOV). Further research still needs to be conducted to address the thorny issue of how much resolution (fidelity) and the level of scene complexity are sufficient for specific training needs. An appropriate method is also needed for measuring and categorizing these two elements. No literature was found to substantiate the FOV recommendations. The recommendation of FOV is used for presentation detail, the specific training task, and audience size. Thus, FOV can be very different across applications and needs to be further addressed.

From the instructional technology literature only general guidelines are available for generic training tasks. Instructional system design (ISD) is required for each training application before any general taxonomic structure can be used. Thus, the taxonomic structure defined in this work is not a substitute for a sound ISD process. Rather it should complement the analysis of task-specific imaging requirements.

Utilization of Findings:

A taxonomy of imaging requirements will help instructional technologists communicate their visual requirements to design engineers. Further, the taxonomy provides a structure that focuses decisions about the relevant characteristics of the image presentation and not merely the means to that end, i.e., display system specifications.

This is a pioneering effort illustrating that minimum specifications for a display system can be structurally linked through human visual functions to address directly the task visual requirements. This taxonomy is an initial building block for more elaborate categorization schemes. It sets the foundation for further development by providing modules of information that can be easily added to, particularly in the experimental expert system form.

Since the taxonomy provides a new organization structure, past research does not easily fit into the format. Therefore often only general trends can be extracted from the literature. The taxonomic framework can help identify further gaps in knowledge, stimulating new research. The taxonomic structure developed allows and encourages the inclusion of new findings that further improves effectiveness and usability. Finally, this taxonomy is not limited to training system design (although that was the primary impetus). The design process lends itself to almost any display application including specific training tasks.

TAXONOMIC TRANSFORMATIONS OF VISUAL MEDIA SELECTIONS INTO DISPLAY SPECIFICATIONS

CONTENTS

Taxonomic Transformations of Visual Media Selections into Display Specifications

Introduction

BACKGROUND

The ability to display veridical visual information for training tasks or for other applications has improved to the point of approaching virtual reality. However, there have been costs. With so many options available in terms of hardware and software design components, it becomes difficult to determine "how much is needed." Traditionally, the choice has been to select the system with the greatest level of functional and physical fidelity that can be procured. While most assume that more realism results in better training and performance, Dwyer (1972) and other Instructional Technologists (Marsh, 1983; Richey, 1986) have disputed that assumption. Dwyer (1978), after reviewing a large body of research that deals with the effects of realism on instruction, concludes "the realism continuum is not an effective predictor of achievement." Realism may add to the information load by adding stimuli that can be distracting, and require more processing. Marsh (1983) developed a matrix for the selection of visual supports for training, which uses less realism and should yield better results under the given set of circumstances.

Thus, after reaching high levels of technical capability, correspondingly more sophisticated choices face users of visual media, ranging from differing presentations to sacrificing certain features. For example: (1) what should be displayed (ranging from degrees of abstraction to concrete reality); (2) how much fidelity will be necessary to display the general types of images chosen, thus influencing system complexity and cost; (3) how can a user be assured that system design capabilities will take advantage of and are not beyond human perceptual capabilities; (4) what choices, and in what order, need to be made to set design requirements; and (5) how will users properly articulate their choices to system engineers as design requirements.

HYPOTHESIS AND VARIABLES

A need exists to organize and define visual media choices and to facilitate the system design by specifying the minimum display requirements for visual characteristics of training systems, and for other applications as well. The experimental questions were threefold, were there any comprehensive organizing structures currently available? If not, what information could be gathered and assembled into a helpful form for users to choose system requirements for themselves? Finally, could end choices be guided and supported by a taxonomic structure to yield at least a description of the minimum presentation requirements for the specific needs of the user.

PURPOSE AND RATIONALE

The objectives of the study are as follows:
(1)Provide guidelines about the type of recommended media for general training situations.
(2)Provide sufficient background for choosing the level of fidelity.
(3)Assure consideration of human perceptual capabilities.
(4)Provide a mechanism for organizing the sequence of choices and for assuring that all major choices have been addressed.
(5)Translate the end choices into concepts and terminology that can be used as engineering design goals.

EXPECTED RESULTS

We anticipated that there would be no existing general structures available in the literature for relating visual image characteristics (needs) to display specifications. It was also expected that sufficient literature was available to build a taxonomic structure as a bridge to relate visual image characteristics to display specifications.

Taxonomic Transformations of Visual Media Selections into Display Specifications

Method

The overall approach was first to determine users' initial training needs by guiding them through a series of questions. The next step was to use those answers to provide a means for facilitating the specification of design objectives of visual display systems to meet those needs. The method considers training guidelines, human visual capabilities and limitations, and engineering display parameters. The strategy was to structure a taxonomy that would (1) assist users in specifying a class of images, (2) relate those images to human visual functions, (3) then translate those image specifications into generic description of visual system characteristics, separate from technology limitations. The final characteristics, as defined, were to be broad enough to allow design flexibility for innovative tailoring of hardware configurations to meet both application and procurement requirements. Yet, it was to be specific enough to achieve the full spectrum of display objectives. The taxonomy also would help engineers identify more clearly the conventional sources available to satisfy imaging requirements while allowing the inclusion of new technologies in appropriate applications. By specifying and categorizing the display characteristics and not the hardware, the taxonomy would not date itself with new technologies. Additionally, the taxonomy would translate technical terms and concepts used by engineers into non-technical information query structures. Thus, once the taxonomic scheme is developed, the engineering functions and terminology will be available in expressions that are more universally used and thus more readily understood by non-engineers.

PROCEDURE

The first step was a selected literature search for relevant information, exiting data bases, or taxonomies that relate visual display characteristics to human visual functions or to visual training requirements. Over 300 articles and books were surveyed from areas of instructional design, human performance, and engineering. The Engineering Data Compendium compiled by Boff and Lincoln (1988) provided excellent documentation for primary human performance data. Instructional Technology considerations were collected from such sources as Flemming and Levie (1978), Marsh (1983), and Richey (1986). Engineering information was obtained through sources such as Perez (1988) and Tannas (1985), from surveys of vendors existing systems[1], and from UCF's Computer Engineering Department. No single reference nor group of references, yielded either direct or summarized data that met the objectives of this study, i.e., an organizing structure for the determination of display characteristics. Some sources gave general guidelines but did not provide specific enough information on the relationship to imaging systems as a whole, for example ". . . visual acuity generally improves with increasing scene luminance" or ". . . increases in display luminance generally degrade display resolution" (Farrell and Booth, 1979).

Finding no developed structure, articles contributing to the proposed taxonomy structure were assembled from instructional technology, human psychology, and engineering. First, since no specific taxonomic structure was available from instructional technology literature for the selection of visual media for given situations, only general guidelines could be cited. Based on those guidelines, four general types of media were selected for presentation user choices: alphanumerics, 2-dimensional graphics, 3-dimensional graphics, and scene quality. Second, with the aid of engineering and vendor-provided design parameters, display specifications were identified as goals for the taxonomy. Third, the taxonomy set up a series of choices for specific user's requirements, upon which human limitations were applied, e.g, the limits of human visual acuity. Based on those choices and limits, psychophysical transformations allowed the determination of final display descriptions.

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[1] Thirty five letters were sent to various simulator vendors querying them with regard to their display design parameters. We obtained 15 responses to these inquiries. The literature received was analyzed for display parameters and utilized in the taxonomic categorization scheme.

The experimental portion of this study was a concept demonstration of the taxonomy as an expert system. With the volume of information and data and the complexity of the taxonomic structure, a user friendly method for presentation was needed. Since much of this information and complexity of organization can be hidden to the user, it lends itself well to a software solution. Expert system software allows a "transparent" simplification for the user, yet retains the full richness of the decision process with on line help available. Thus, selected portions of the taxonomy were entered into an expert system shell, LEVEL V by Information Builders, Inc., as a concept demonstration.

Taxonomic Transformations of Visual Media Selections into Display Specifications

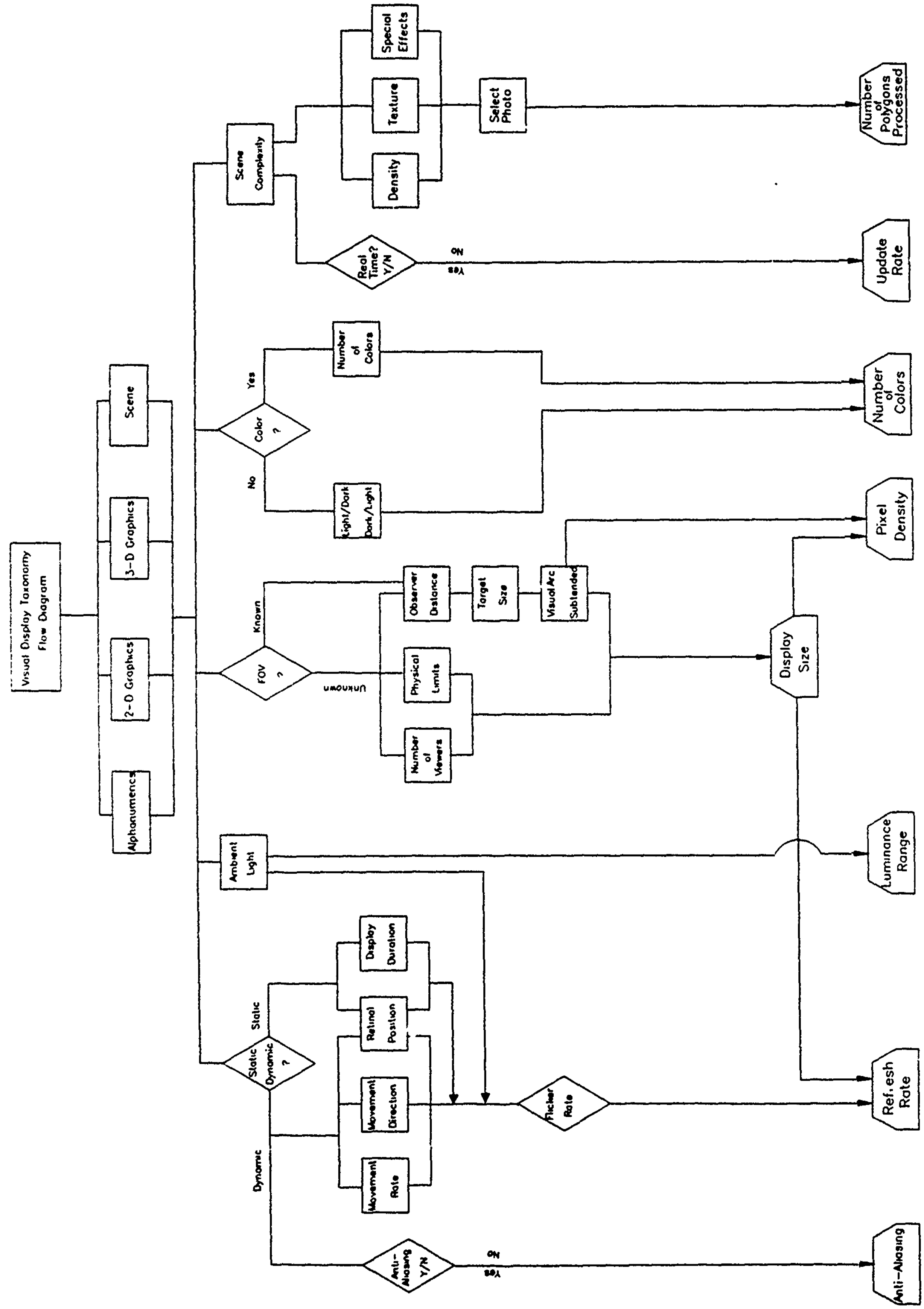
Result

SUMMARY
The overall result is a taxonomic structure capable of analyzing visual media requirements into a generic system description. The final description has eight display parameters, easily translatable into specifications by a design engineer. It is important to note the difference between description and specification. As a system description, the taxonomy makes no attempt to predict or anticipate the current level of technology as it relates to visual displays. The sophisticated (and most probably, expensive) today will be viewed as primitive tomorrow. This study relates basic visual stimuli needs with the human visual system to a <u>description</u> of system requirements that would meet those needs. It is then the task of the engineer to design a system specification that will meet the requirements described.

The figure on the following page shows a system decision flow diagram leading to visual system characteristics developed for the overall taxonomy. The taxonomy finally branches into characteristics of systems such as refresh rate, display size, pixel density, and luminance range.

The flow diagram structure incorporates diamond shaped boxes for decisions, rectangular boxes for actions, and polygons for final system specifications. The decision progress follows a "top-down" fashion, with decision points from the upper levels of the taxonomy to the lower levels until finally reaching each system characteristic.

The same decision flow diagram is appropriate for both the paper taxonomy and the electronic form as an expert system. The two systems have parallel structure. The advantage of the expert system is that it automatically prompts the user with a question at each decision point, then selects the branches based on the user's input. The final listing is a complete inventory of system characteristics, as the basis for final engineering specifications.



Visual Display Taxonomy
Flow Diagram
Alphanumerics
2-D Graphics
3-D Graphics
Scene
Scene Complexity
Density
Texture
Special Effects
Select Photo
Number of Polygons Processed
Real Time? Y/N
Yes
No
Update Rate
Color ?
Yes
No
Number of Colors
Light/Dark Dark/Light
Number of Colors
FOV ?
Known
Unknown
Observer Distance
Target Size
Visual Arc Subtended
Physical Limits
Number of Viewers
Display Size
Pixel Density
Ambient Light
Luminance Range
Static Dynamic ?
Static
Dynamic
Display Duration
Retinal Position
Movement Direction
Movement Rate
Flicker Rate
Refresh Rate
Anti-Aliasing Y/N
Yes
No
Anti-Aliasing

As an example of this process, consider the resulting description from the taxonomy for resolution with an electronic display. Based on visual angle, object size, and viewer distance, the taxonomy may recommend a resolution of 700 x 510 pixels. Presently, there is no visual display with those exact specifications. Of course, it is possible to have a display unit designed and constructed to this specification, but only at great expense. The engineer, in this instance, could select a standard resolution screen of 640 x 480 pixels if cost were a primary concern. Or a higher standard of 1024 x 512 pixels if full resolution was critical to the training requirement.

A more difficult transformation is to relate scene complexity as a stimulus to a system description. In this regard, we provided stepped examples based on computer generated example scenes and have assigned complexity levels. The number of polygons that the computer must generate to create the scene represents the complexity range. Given this information, the engineer can specify the computer performance needed to meet the required level of scene complexity generation. Factors such as real-time performance, scene storage, and hybrid scene generation requirements can be addressed.

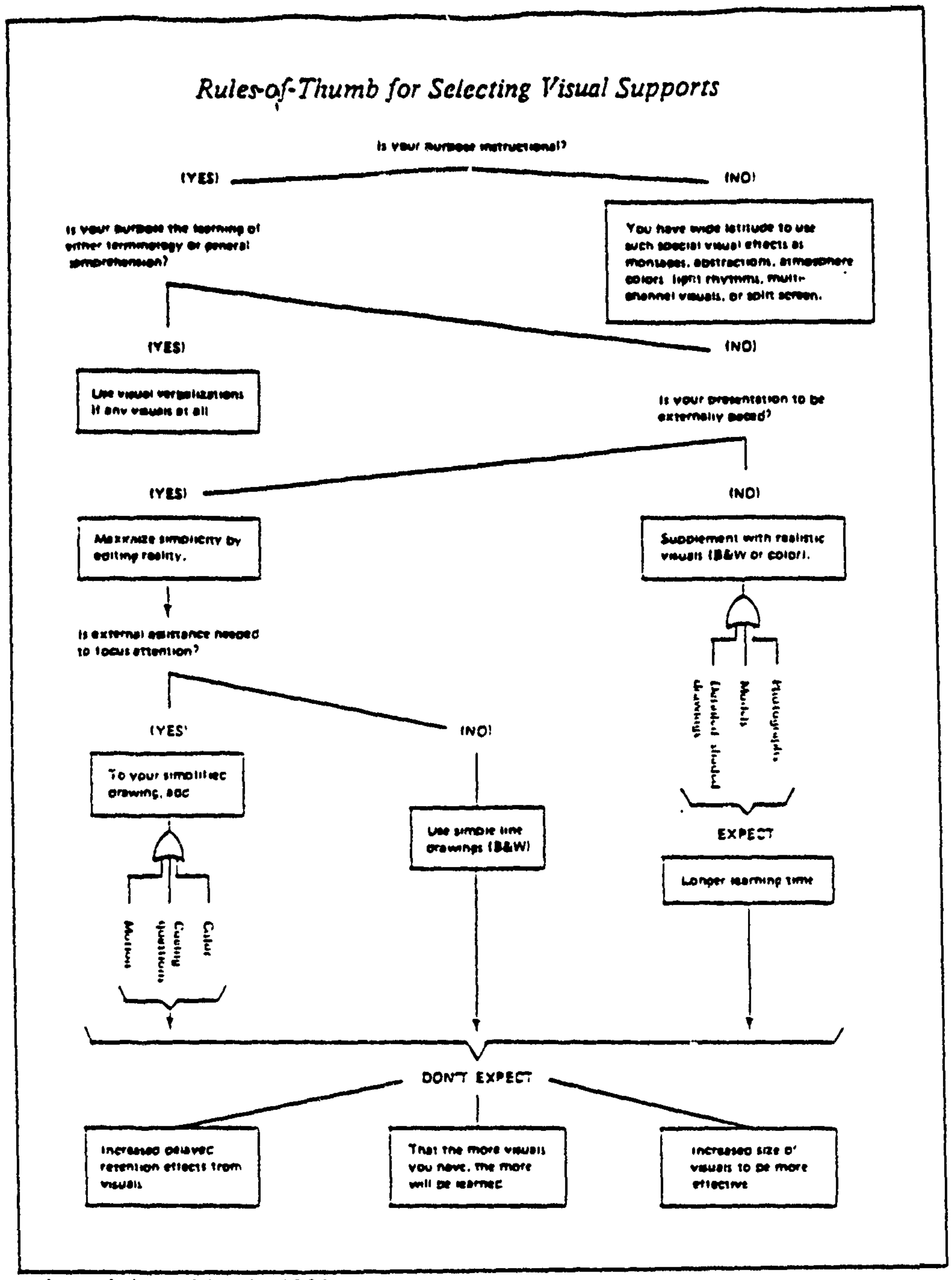
INSTRUCTIONAL CONSIDERATIONS

This taxonomy does not claim to analyze the problem of media selection for the user. The following section provides general guidelines in the media selection process appropriate for the first step into the taxonomy. This is not to substitute for a thorough application of instructional technology methods, such as the Instructional System Design (ISD) process analyzing a specific training task. Specific applications of visual media are not possible without detailed knowledge of the training task and thus are not available "a priori" to the taxonomy. In most Instructional technology manuals the choice of the most appropriate script, language style and graphical presentation is left to the user. Guidelines are at the general level based on audience sophistication and readiness to learn. Thus, according to Marsh (1983, p93) "there are so many possibilities for creating visual variety that no check list could be adequate."

Still, there are some principles for media selection as included below that can serve as a precursor to the entry into the taxonomy for image specifications.

At the beginning of the text of the taxonomy, the user will be asked to consider some initial requirements pertaining to image content. The first of these requirements will be the decision for the type of information that needs to be displayed to the viewer (i.e., two-dimensional alphanumerics, two-dimensional graphics, three-dimensional graphics, or three-dimensional scenes). These requirements will lead to decisions about levels of resolution, color, and complexity and whether a dynamic display or a static display is best suited for the training task. Also, the screen size and whether to have an interactive system will need to be determined. It is the purpose of this section to provide the user with some background information for questions concerning these initial requirements.

According to Dwyer (1972), and Marsh (1983), the following is a "rules of thumb" guide for selecting visual supports. This should aid the user of this taxonomy in deciding the type of visual images that will be best suited for the information to be presented.



Adapted from Marsh, 1983.

Once the type of information to be displayed is established , the next step is to consider the audience (trainees) who will be viewing that information. The following is a chart from Marsh (1983) that describes the audience according to their sophistication and readiness levels. Following the chart are Marsh's definitions of the terms used.

SOPHISTICATION

READINESS	H	M	L
H	ELITE (Expert) Abstracted Reality Low Definition	PROFESSIONAL (Responsible) Interpreted or Distorted Reality Low Definition	OVER-ACHIEVER (Dedicated) Representational Reality Low Definition
M	DISPLACED EXPERT (Quick Starter) Abstracted Reality Moderate Definition	MODAL (Competent) Interpreted or Distorted Reality Moderate Definition	LAY AUDIENCE (Popular) Representational Reality Moderate Definition
L	UNDER-ACHIEVER (Slow Starter) Abstracted Reality High Definition	RANK and FILE (Adult Workforce) Interpreted or Distorted Reality High Definition	MASS AUDIENCE (Common Denominator) Representational Reality High Definition

Basic Graphics Matrix for Decisions Based upon Receiver-Imposed Constraints (Marsh, 1983, p.128)

Definitions:

Representational reality is created by visual materials that are realistic, objective, concrete, and commonplace. Photography provides the best means of capturing representational reality, especially when shot with a normal lens in normally lighted situations.

Interpreted or distorted reality represents an object subjectively as it might be seen through the unique goggles of an interpreter. For example, a photograph shot from an unusual angle, under special lighting effects, or with a distorting lens tends to filter objective reality through the interpreter's nervous system to provide a symbolic or artistic rendering of the object. In a similar way, a cartoonist or caricature artist interprets reality by distorting it. Verbal accompaniment is more appropriate at this level than at the representational level where the graphic often speaks for itself.

Abstracted reality is created by extracting the essential qualities, minimizing the uniqueness of the object, and emphasizing its generality or universality. It is symbolic and suggestive - often more subtle than interpreted reality. It represents a transformation from species to genus and thus is more compatible with conceptual interpretations.

High definition in graphics is achieved in part by framing the object in a large enough frame to capture the context without destroying it. Grainy or half-toned photographs tend to reduce definition without destroying the subtly or texture.

Low definition is suitable for high readiness, isolates the figure and often suppresses the context. Mounting the isolated figure on a light gray background is a common way of suppressing the context or background. Simple black and white line drawings (with color added only for emphasis), especially when framed narrowly, generate a somewhat stark isolation that minimizes distraction.

These media levels relate well to the initial taxonomic choices of alphanumeric, 2-D graphics, 3-D graphics, and scenes. For example, representational reality relates to scenes, while abstracted reality may relate best to 2-D graphics. Now armed with the knowledge of the type of information that needs to be displayed and the audience who will be viewing the information, we will include a summary of Dwyer's (1972) "A Guide for improving Visualized Instruction":

"Summary of General Conclusions

1. Determine whether visual supports are justified. (For learning terminology or for general comprehension, they tend to contribute little.)
2. Edit reality as much as the situation will allow when viewing time is controlled or limited.
3. Add color to edited visual to heighten attention.
4. Do not expect increased delayed retention effects form visual supports.
5. Larger images do not necessarily add to instructional effectiveness.
6. Motion tends to focus attention to desired parts of a visual supports.
7. Questions do not make very effective attention focuses in realistic visuals.
8. Questions help to focus attention on simpler illustrations.
9. Realism for self-paced instruction; simplicity for oral supplement."

To begin this taxonomy for training system design, certain aspects need to be considered. First, this taxonomy is unique; we could find no other comprehensive taxonomy for visual display systems. Information has been gathered from a variety of sources across a range of disciplines. These disciplines include psychology, engineering, and instructional technology. The psychological aspects include information with respect to sensation, perception, cognition, basic learning, and complex human learning. From an engineering standpoint, the taxonomy includes the necessary data a trainer will need to communicate with engineers who design visual display systems. Finally, from instructional technology the taxonomy includes research findings concerning the best approach to teaching different types of information or training someone at various levels.

This taxonomy fits well with the increasing use of Computer Assisted Instruction (CAI). Much of the taxonomy is directly applicable to CAI video displays and image content. Computer Assisted Instruction not only provides for receiver control, but also attempts to establish personalized interactions with the learner. Increasing emphasis is on the nature of the questions embedded in CAI programs. There has also been considerable work extending the theories of media effectiveness to computer applications. Current research and development relates to computer use for personal communication and learning. This includes concern with the attitudes of learners toward communicating with machines.

The remainder of this *Results* section contains the body of the taxonomy along with the experimental expert system source code. This body of the taxonomy is divided into two main sections: *Alphanumerics* and *Graphics*, and each of those sections is divided into the *Initial Considerations* and *Final Image Descriptions*.

Taxonomy of Visual Display Systems

INTRODUCTION

Before beginning to use this taxonomy, the user needs to be aware of some "pre-taxonomy" information. Through the use of instructional technology knowledge, the user should know which particular instructional presentation will be most appropriate for the training needs, and should be chosen from the following categories: two-dimensional alphanumerics, two-dimensional graphics, three-dimensional graphics, or three dimensional scenes. The user should gather needed information concerning approximate audience size, where the display will be housed (will it be physically constrained in a small area?), will there be needed viewer interaction with the system, lighting conditions where the display will be housed, and any information that has been pre-determined as a "must" for this visual display system.

If an alphanumeric presentation will be used, turn to page 11 to begin the taxonomy's initial considerations. Make sure you have paper handy, as you will need to jot down answers to a number of considerations. Beginning with page 40, you will work through the final image descriptions using the answers to the questions in the initial considerations section. If a graphical presentation (albeit two-dimensional, three-dimensional, or scene quality) is needed, turn to page 56 to begin the taxonomy's initial considerations. Jot down answers to all questions in this section for use in the final image descriptions section for graphics (beginning on page 88).

ALPHANUMERICS

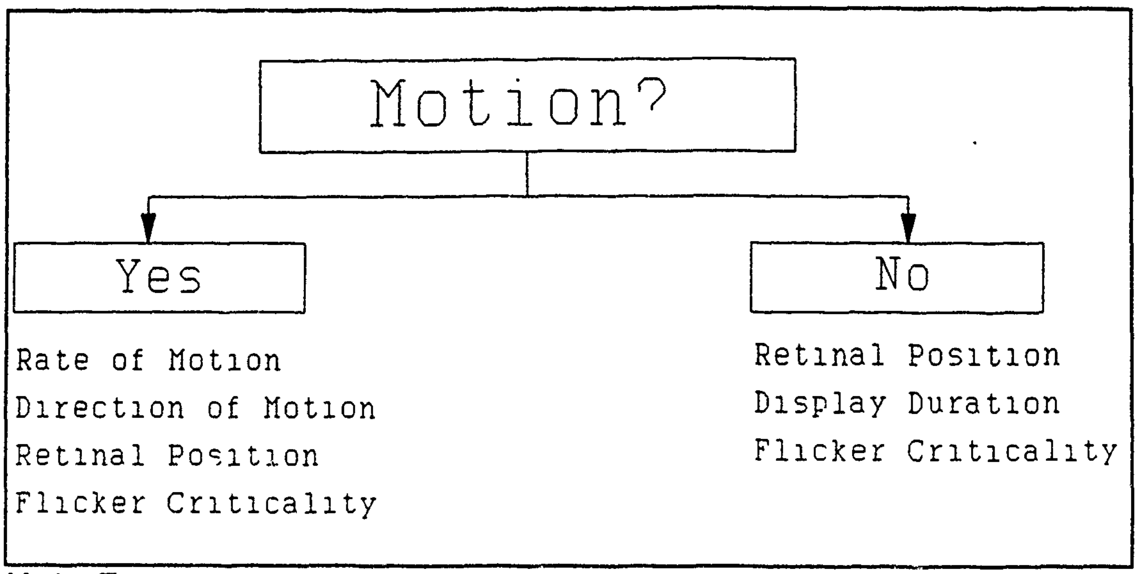
You have chosen to display two dimensional alphanumerics as your most complex display image. Alphanumeric images include letters and numbers only.

How to use the Initial Considerations Section of this Taxonomy

The following section contains only those elements that are essential in defining a visual display system designed for alphanumeric images. At the beginning of each subsection you will find a simple tree diagram of the initial requirement. This diagram will include the root (upper most box) which is the general area of concern. From the root, either a single path may be followed or a decision will need to be made between two broad elements. Following each of these branches will be a list of specific topics that choices will be made from.

Following each diagram will be background information, explanations, and definitions concerning the topic area. This information may be helpful in calculating the needed information described in the diagram. At the end of each subsection, a specific question will be asked. These questions will be found in shaded boxes, and they correlate directly to the final image descriptions. It is important to have an answer for each question in order to accurately transfer needed information to the final image descriptions.

Static versus Dynamic Display



Motion Tree

DYNAMIC DISPLAY

Motion--
YES

If you answered "yes" to motion, then you have chosen a dynamic display system. The following information will guide you through the constraints and factors of a dynamic visual display system.

According to Sanders and McCormick (1987), dynamic information is information that continually changes or is subject to change. Some examples of dynamic information include traffic lights, speedometers, and radar displays. The intent of the dynamic visual display in this section is to create motion of the alphanumeric image. This type of motion could involve automatic scrolling of text either vertically or horizontally. The difference between the static and dynamic displays with respect to motion of the image is that in a static display the viewer controls the motion, while in a dynamic display, the image can be in motion without any manipulations from the viewer. For dynamic alphanumeric displays, the motion rate will probably need to be slow enough such that the images are legible. The constraints to be used in determining the dynamic display characteristics are: (1) the rate of motion of the image across the screen, (2) the direction of the motion, (3) retinal position of the observer(s), and a (4) flicker criticality level. Once again, the responses obtained from this section correlate to the final image descriptions and relationships to system design.

Rate of
Motion

Rate of motion can be defined as the rate of speed that an object (or text) moves across the screen. This rate needs to be stated in degrees per second. The following table can be utilized to make conversions between miles per hour (or feet per second) and degrees per second.

Miles per Hour	Feet per Second	Degrees and Seconds									
100	146	164° 24'	149° 22'	135° 20'	122° 34'	111° 24'	101° 10'	92° 24'	84° 46'	78° 6'	72° 16'
80	118	160° 46'	142° 34'	126° 6'	111° 4'	99° 26'	89° 2'	80° 16'	72° 50'	66° 30'	61° 6'
70	102	157° 10'	136° 24'	119° 6'	103° 8'	91° 8'	80° 44'	72° 10'	65° 2'	59° 6'	54° 4'
60	88	154° 24'	131° 8'	111° 26'	95° 28'	82° 42'	72° 32'	64° 18'	57° 38'	52° 8'	47° 30'
50	74	149° 6'	123° 14'	101° 16'	85° 34'	72° 62'	63° 20'	55° 44'	49° 40'	44° 42'	40° 38'
40	58	141° 18'	110° 50'	88° 4'	71° 14'	60° 14'	51° 36'	45° 2'	39° 52'	35° 44'	32° 22'
30	44	131° 8'	95° 28'	72° 32'	57° 38'	47° 30'	40° 18'	34° 54'	30° 48'	27° 30'	24° 50'
20	29	110° 50'	71° 44'	51° 36'	39° 12'	32° 22'	27° 12'	23° 24'	20° 34'	18° 18'	16° 32'
15	22	95° 28'	57° 38'	40° 18'	30° 46'	24° 50'	20° 48'	17° 52'	15° 40'	14°	12° 38'
10	15	73° 6'	41° 8'	28° 6'	21° 16'	17° 4'	14° 16'	12° 34'	10° 44'	9° 32'	8° 36'
8	12	61° 56'	33° 24'	22° 38'	17° 4'	13° 42'	11° 26'	9° 48'	8° 36'	7° 38'	6° 54'
5	7	38° 36'	19° 12'	13° 20'	10°	8° 2'	6° 42'	5° 50'	5° 2'	4° 28'	4° 2'
2	3	17° 4'	8° 36'	5° 4'	4° 18'	3° 26'	2° 52'	2° 28'	2° 10'	1° 56'	1° 44'
		10	20	30	40	50	60	70	80	90	100

Angular Speeds of Objects along a Path of Travel for Various Speeds and Distances (Salvendy, 1987).

Movement rates of less than 40 degrees per second will retain image visibility for identification purposes. The eye will be able to track motion smoothly, at least in the horizontal direction, up to velocities of about 30 degrees per second (Farrell and Booth, 1984). According to Boff and Lincoln (1988), the dynamic visual acuity (visual resolution of a moving target) decreases as the angular velocity between a target and an observer increases; regardless of whether the target or the observer is moving. In other words: as the rate of motion increases, the rate of visual acuity (and therefore perceived resolution) decreases. One way to increase dynamic visual acuity is to increase the illumination as the angular velocity is increased (Boff and Lincoln, 1988).

According to Farrell and Booth (1984), one effect of moderate velocities of image motion on the viewer is to limit the time he can spend looking for a particular character or a set of characters. For example, with an image velocity of 20 degrees per second and an image field of 40 degrees, a single point on the image will be visible no longer than two seconds. Assuming each eye fixation lasts an average of 0.4 seconds, the observer is allowed only 5 fixations, in this example, to cover the entire image field.

Also according to Farrell and Booth (1984), image velocities of two to 30 degrees per second can be viewed with comfort if all "jerkiness" is removed, but disparity in the image will cause discomfort in some users. Velocities of 60 to 90 degrees per second should not be used in alphanumerics as the viewer would not be able to discern individual characters. Searching for a particular character would certainly not be a possibility at this velocity.

When the rate of motion is low (up to 10 degrees per second), there is little difference between static and dynamic displays (Farrell and Booth, 1984). Taking a look at the scale below, the "low" motion rate would probably allow high visual acuity without changing illumination or display size. Th "medium" motion rate may require some adjustments to be made to either illumination levels or to the display size. Finally, a selection of the "high" motion rate would definitely require adjustments to be made in other contributing factors. These "factors" and adjustments are taken into account in the final image descriptions to be computed at the end of this taxonomy.

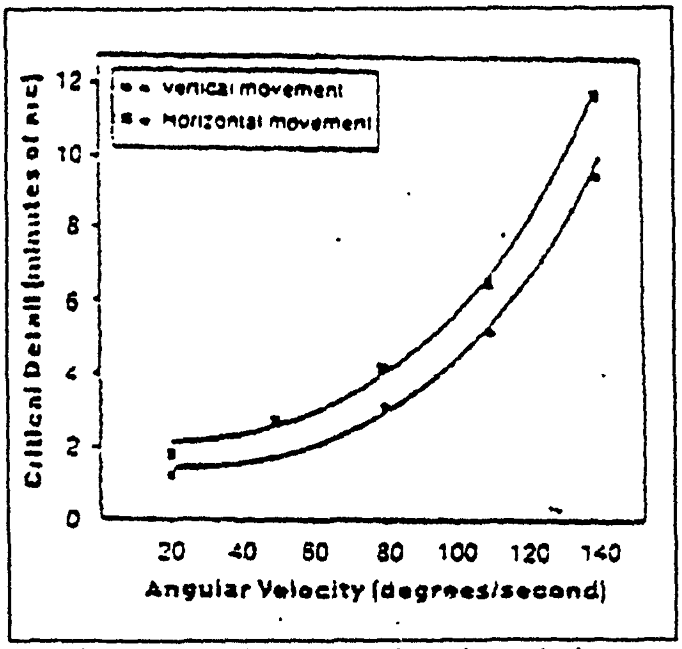
What is the rate of motion across the screen (per second)?

_______ low : 0° - 20°
_______ medium : 20° - 40°
_______ high : 40° - 100°

Movement Rate

Direction of Motion

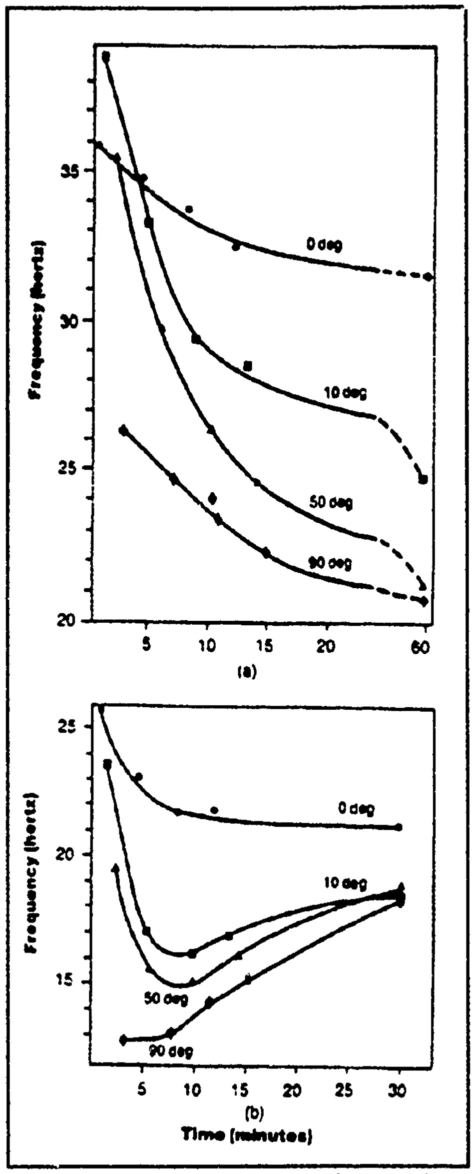
The direction of motion for the image may be horizontal, vertical, oblique (diagonal), or any combination of the three. According to Booth and Farrell (1979), image velocities of up to about 2.5 degrees per second can be tolerated if the motion is horizontal or vertical, whereas, if the motion is in an oblique direction, a velocity of only one degree per second reduces visibility. Normally, a display system will be capable of not only horizontal motion or oblique motion only. Therefore, for the purposes of calculating the final image specification in this taxonomy, we will assume the most difficult direction to obtain is necessary, and use the calculation based on oblique direction. As added information for the curious user, the following figure illustrates the effects of visual acuity with target motion in the horizontal and vertical directions:



Visual acuity with horizontal and vertical target movement. The ordinate gives the smallest resolvable gap size in a moving Landolt-C target (Miller, 1958).

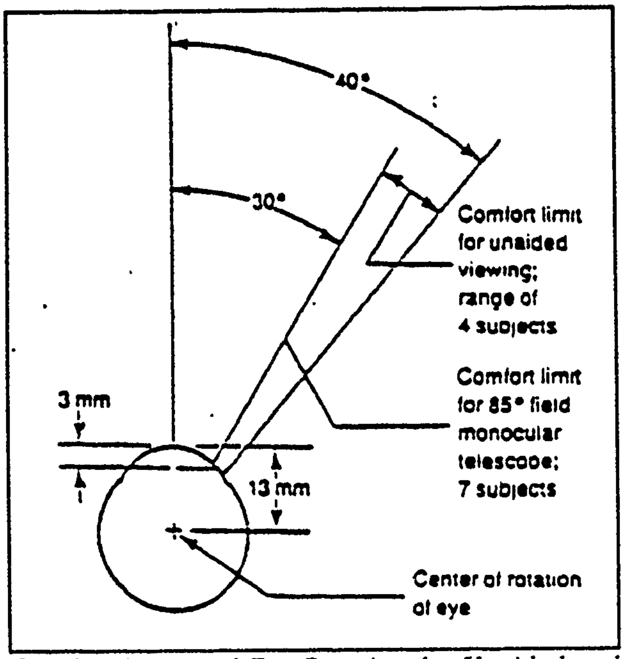
Retinal Position

The retinal position is a determinant in the critical flicker frequency. The CFF depends on the time-averaged luminance of the flickering target, its location in the visual field, and the observers' state of adaptation (Boff and Lincoln, 1988). Highest CFF values are found for light adapted observers looking at foveal targets. This relationship is pictured in the following figure.



Critical flicker frequency during dark adaptation. CFF is shown as a function of time in the dark for targets at various angular distances from fixation, as indicated on curves (Lythgoe & Tansley, 1929).

The maximum field of view (FOV) of the normal observer, under the best conditions, is a somewhat irregularly shaped ellipse made up of overlapping monocular fields of the right and left eyes. The FOV extends to approximately 60 degrees of visual angle above and below the center and more than 100 degrees to the left and right (Boff and Lincoln, 1988). (It may be important to note that this visual field declines with adults over 30 to 35 years of age.) The following figure illustrates the comfort limits of eye rotation for unaided and aided viewing. As this figure shows, 30 degrees (and in some instances, up to 40 degrees) should be the maximum visual angle used for comfortable viewing.



Comfort Limits of Eye Rotation for Unaided and Aided Viewing (Farrell & Booth, 1984).

Research indicates that sensitivity to flicker is greater for peripheral targets than for foveal targets (Kelly, 1972 and Kulikowski & Tolhurst, 1973). Maximum sensitivity to light occurs when the angular distance of the target from the fixation point is approximately 20 degrees. Sensitivity to light increases as the distance from fixation increases from 0 degrees to 12-22 degrees. This sensitivity remains fairly constant until 32 degrees, and then it begins to decrease with additional increases in angular target distances from the fovea (Riopelle and Bevan, 1953).

The following question is needed for determination of refresh rate in the final section. The information supplied needs to be stated in degrees, and needs to state how far into the peripheral field of view the displayed image will be located.

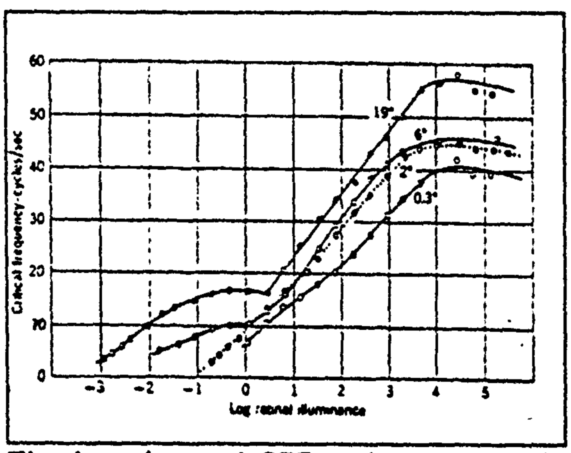
Where does the object fall on the observers' retina?

_________ at fixation position
_________ less than 5° from fovea
_________ between 5° and 30° from fovea
_________ greater than 30° from fovea

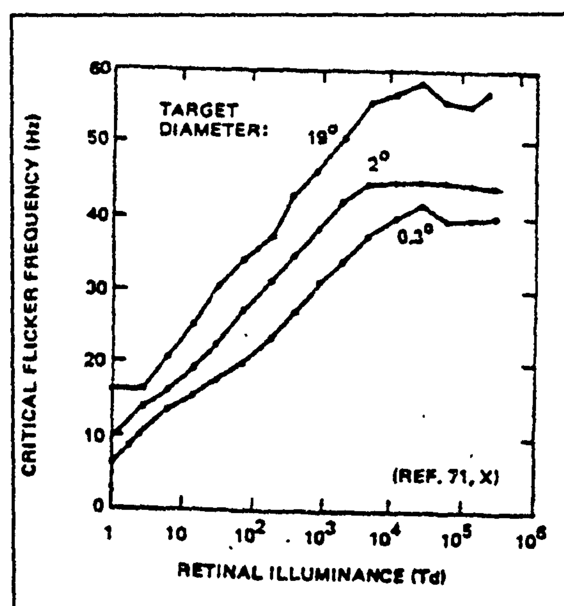
Retinal Position

Flicker Criticality

First of all, there are too many variables that affect critical flicker frequency (CFF) to allow setting a single value that can serve as a design limit in all situations (Farrell and Booth, 1984). There are, however some guidelines that can be followed. According to the Boff and Lincoln (1988), the detectibility of a flickering target depends on the luminance of its background. In general, a flickering target will be less visible the higher the background luminance (Boff and Lincoln, 1988). The flicker fusion frequency can be defined as the alternating rate at which fusion of the flickering sources occurs and thus becomes perceptually one source, and the lowest possible flicker fusion frequency is in the 10 Hertz (Hz) range. Under normal lighting, this range will produce a high rate of flicker. The visual system is more sensitive to flicker as brightness increases (Farrell and Booth, 1984). The following figures illustrate the relationship between retinal illuminance and critical flicker frequency.



The dependence of CFF on luminance. The different curves refer to diameter of the test field (Hecht & Shlaer, 1936).



Graph of CFF as a function of target diameter and retinal illumination (Farrell & Booth, 1984).

Thus, as the graphs indicate, the 10 Hz range may be acceptable under certain circumstances (i.e. low retinal illuminance). The typically acceptable flicker fusion frequency, in cycles per second, is in the 30 Hz range, although some flicker will occur at this frequency. For most viewing situations an image depicted at a frequency of 60 Hz does not appear to flicker. As display sizes increase, the flicker frequency will need to increase in order to maintain the same level of flicker; i.e., for surfaces larger than 20 degrees with a luminance greater than 340 cd/m^2 (100 fl), 80 Hz is usually adequate (Farrell and Booth, 1984). The following list has been adapted from Farrell and Booth (1984), and gives the general principles governing flicker frequencies:

- CFF increases with luminance
- CFF increases with target area size
- Periphery CFF may be higher or lower than at fixation...Large target sizes show more flicker in the periphery
- CFF increases as temporal modulation increases
- CFF varies with duration of light and dark intervals
- Large variability in flicker sensitivity of individuals
- For test areas greater than one degree, surround luminance has no effect of CFF
- Very brief and high luminance flashes raise the CFF higher than would be predicted by luminance averaged over time.

With all this information in mind, a determination needs to made with regard to the level of flicker that will be allowable in the visual display system being considered at this time.

How critical is the removal of flicker from the display?

_______ Critical : Must be eliminated as much as possible
_______ Important : Flicker may occur in some instances
_______ Non-critical : Flicker is acceptable

Flicker Criticality

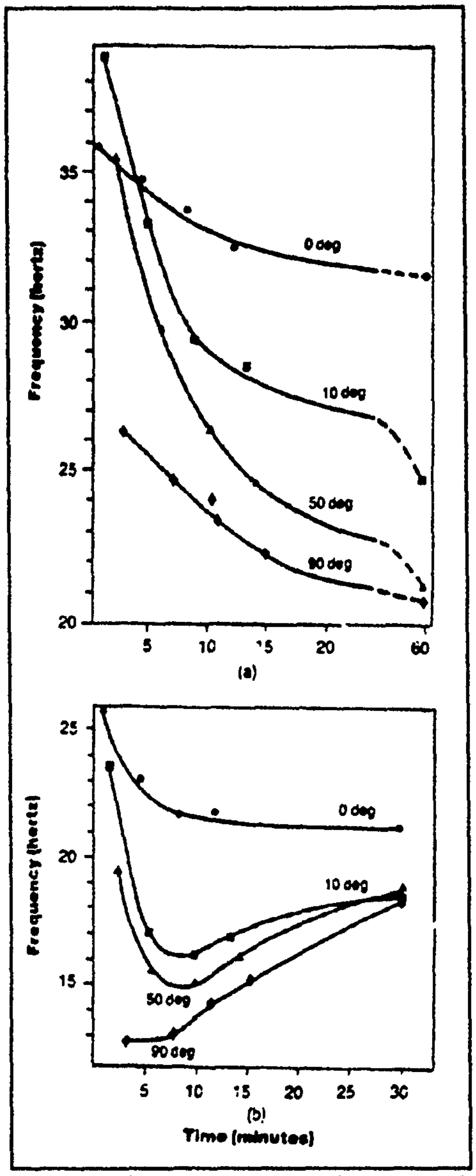
Motion--
NO

STATIC DISPLAY

If you answered "no" to motion, then you have chosen a static display system. The intent of the static display is to present information in a non-moving format. The assumption of choosing a static display is that neither the observer nor the displayed information will be in motion. In order to create a static display, there are a couple of items to consider. First, for a cathode ray tube (CRT) presentation which turns on and off, there will be a need to eliminate flicker in order for the presentation to be considered static. Secondly, there will need to be a minimum amount of presentation time as required by the user. We will also look at retinal position in this section as it will be a determination in the final image specification for refresh rate. Once again, the responses obtained from this section correlate to the final image descriptions and relationships to system design.

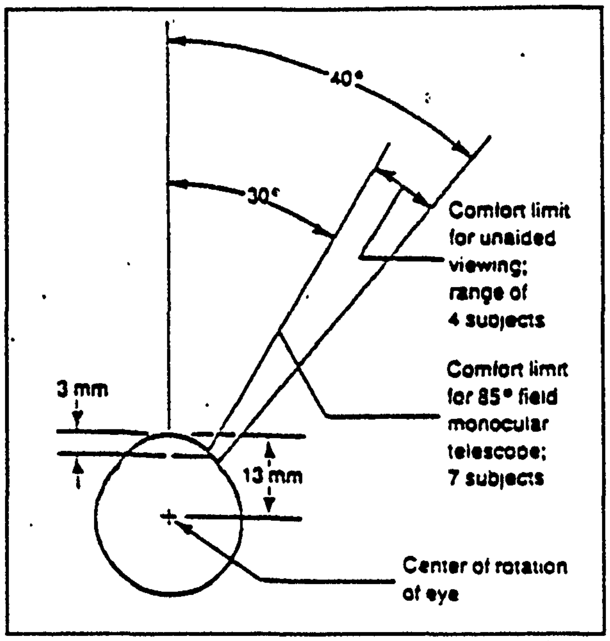
Retinal Position

The retinal position is a determinant in the critical flicker frequency. "Critical flicker frequency (CFF) is defined as the lowest frequency at which a light will be perceived as anything but a steady light" (Boff and Lincoln, 1988). The CFF depends on the time-averaged luminance of the flickering target, its location in the visual field, and the observers' state of adaptation (Boff and Lincoln, 1988). Highest CFF values are found for light adapted observers looking at foveal targets. This relationship is pictured in the following figure.



Critical flicker frequency during dark adaptation. CFF is shown as a function of time in the dark for targets at various angular distances from fixation, as indicated on curves (Lythgoe & Tansley, 1929).

The maximum field of view (FOV) of the normal observer, under the best conditions, is a somewhat irregularly shaped ellipse made up of overlapping monocular fields of the right and left eyes. The FOV extends to approximately 60 degrees of visual angle above and below the center and more than 100 degrees to the left and right (Boff and Lincoln, 1988). (It may be important to note that this visual field declines with adults over 30 to 35 years of age.) The following figure illustrates the comfort limits of eye rotation for unaided and aided viewing. As this figure shows, 30 degrees (and in some instances, up to 40 degrees) should be the maximum visual angles used for comfortable viewing.



Comfort Limits of Eye Rotation for Unaided and Aided Viewing (Farrell & Booth, 1984).

Research indicates that sensitivity to flicker is greater for peripheral targets than for foveal targets (Kelly, 1972 and Kulikowski & Tolhurst, 1973). Maximum sensitivity to light occurs when the angular distance of the target from the fixation point is approximately 20 degrees. Sensitivity to light increases as the distance from fixation increases from 0 degrees to 12-22 degrees. This sensitivity remains fairly constant until 32 degrees, and then it begins to decrease with additional increases in angular target distances from the fovea (Riopelle and Bevan, 1953).

The following question is needed for determination of refresh rate in the final section. The information supplied needs to be stated in degrees, and needs to state how far into the peripheral field of view the displayed image will be located.

Where does the object fall on the observers' retina?

_________ at fixation position
_________ less than 5° from fovea
_________ between 5° and 30° from fovea
_________ greater than 30° from fovea

Retinal Position

Display Duration

The minimum presentation time will be designated by the user. If the presentation time is greater than 100 milliseconds (msec), and if the presentation medium is computer generated, then no consideration for presentation time is needed. If, however, the required presentation time is less than 100 msec, the exact presentation time needed will be required for technical specifications. It is important to note the effect of shorter presentation times: Below 100 msec, the eye will not perceive changes in duration of the target, but will perceive changes in the intensity of the target. Therefore, if you were to continually lessen the target duration time, the target would appear to be "fading away" as the intensity decreased toward the point of nonexistence.

If your presentation time needs to be less than 100 msec, a presentation time should be chosen from the following list. If the presentation time is equal to, or greater than, 100 msec, this box should be skipped.

Please choose the minimum display duration from below:

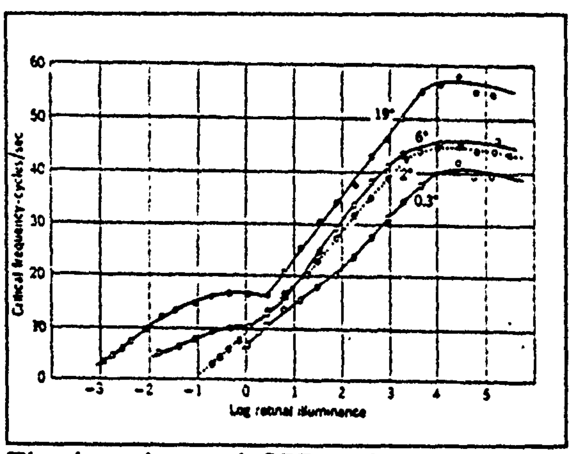
_______ 80 msec _______ 50 msec _______ 33 msec

_______ 25 msec _______ 20 msec _______ 15 msec

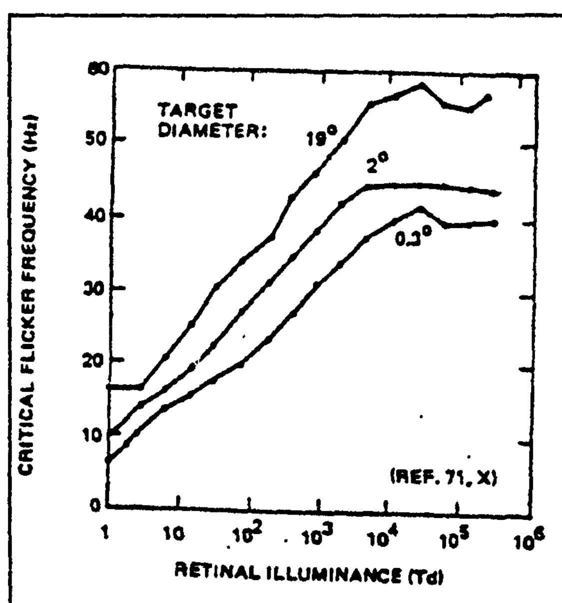
Minimum Display Duration

Flicker Criticality

First of all, there are too many variables that affect critical flicker frequency (CFF) to allow setting a single value that can serve as a design limit in all situations (Farrell and Booth, 1984). There are, however some guidelines that can be followed. According to Boff and Lincoln, 1988, the detectibility of a flickering target depends on the luminance of its background. In general, a flickering target will be less visible the higher the background luminance (Boff and Lincoln, 1988). The lowest possible flicker fusion frequency is in the 10 Hertz (Hz) range. Under normal lighting, this range will produce a high rate of flicker. The visual system is more sensitive to flicker as brightness increases (Farrell and Booth, 1984). The following figures illustrate the relationship between retinal illuminance and critical flicker frequency.



The dependence of CFF on luminance. The different curves refer to diameter of the test field (Hecht & Shlaer, 1936).



Graph of CFF as a function of target diameter and retinal illumination (Farrell & Booth, 1984).

Thus, as the graphs indicate, the 10 Hz range may be acceptable under certain circumstances (i.e. low retinal illuminance). The typically acceptable flicker fusion frequency, in cycles per second, is in the 30 Hz range, although some flicker will occur at this frequency. For most viewing situations an image depicted at a frequency of 60 Hz does not appear to flicker. As display sizes increase the flicker frequency will need to increase in order to maintain the same level of flicker; i.e., for surfaces larger than 20 degrees with a luminance greater than 340 cd/m^2 (100 fl), 80 Hz is usually adequate (Farrell and Booth, 1984). The following list has been adapted from Farrell and Booth (1984), and gives the general principles governing flicker frequencies:

- CFF increases with luminance
- CFF increases with target area size
- Periphery CFF may be higher or lower than at fixation...Large target sizes show more flicker in the periphery
- CFF increases as temporal modulation increases
- CFF varies with duration of light and dark intervals
- Large variability in flicker sensitivity of individuals
- For test areas greater than one degree, surround luminance has no effect of CFF
- Very brief and high luminance flashes raise the CFF higher than would be predicted by luminance averaged over time.

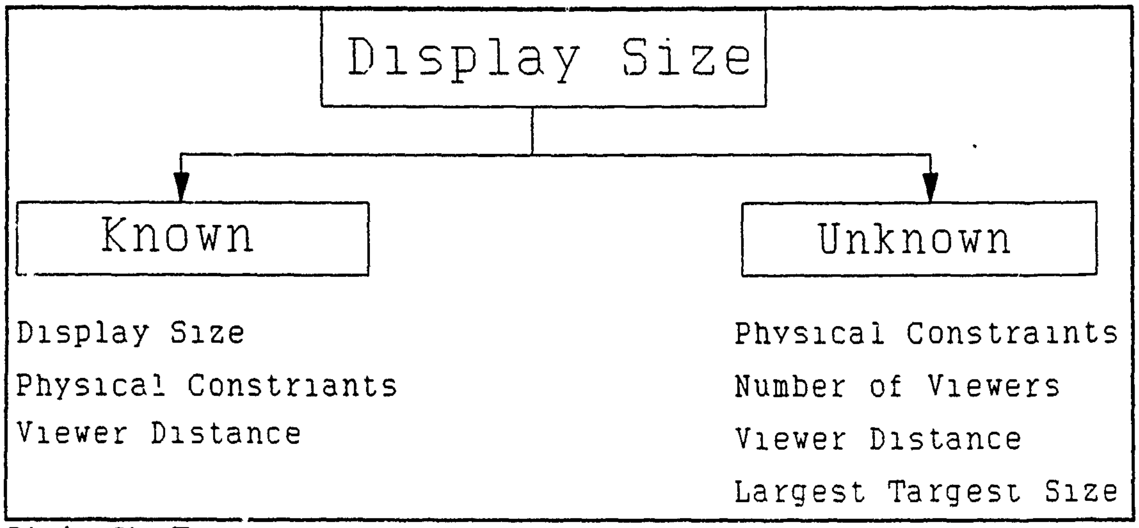
With all this information in mind, a determination needs to made with regard to the level of flicker that will be allowable in the visual display system being considered at this time.

How critical is the removal of flicker from the display?

_______ Critical : Must be eliminated as much as possible
_______ Important : Flicker may occur in some instances
_______ Non-critical : Flicker is acceptable

Flicker Criticality

DISPLAY SIZE CONSIDERATIONS



Display Size Tree

Display Size--Known

KNOWN DISPLAY SIZE

With the exception of a general consensus that big is good, there is no basis at present for firm design limits on display field size (Farrell and Booth , 1984). Since it is difficult to specify display sizes based on tasks without fully knowing the task's individual requirements (Marsh, 1984), determination of display size is best left up to the instructional designer as he is more intimate with the task at hand. If you said "known" to display size in the diagram, and there are no definite, (small-physical) constraints, then the size of the display may be chosen from a wide assortment of sizes. If there is a known physical constraint please see the section below labeled by that name. The viewer distance will also be determined in this section for use in the image descriptions of pixel density.

Display Size

If the needed display size is known and is at least 13" (measured diagonally), then a choice should be made from the following list. If the needed display is less than 13", skip the following list and use the physical constraints information found in the next section.

Please choose an appropriate visual display size from the list below (all sizes are measured diagonally, in inches):

_______ 13	_______ 17	_______ 19	_______ 21
_______ 25	_______ 36	_______ 120	_______ >120

Display Size

Physical Constraints

Sometimes the area allotted in the design of a system has been determined by engineering descriptions which are completed for an entire environment (such as a real-life simulator). A visual display panel, such as one that may be used in the modeling of a fighter aircraft, may be allotted only a five inch square surface area for visually displaying information. Obviously in a case such as this, a thirteen inch diagonal screen becomes unusable. If there are known physical constraints that require the chosen display size to fit into a small area, please choose from among the physical constraints categories shown below to determine the appropriate display size.

Please choose the category below that best describes the physical space limitation (in inches):

_______ 4 x 3 x 5	_______ 8 x 6 x 9
_______ 19 x 12 x 15	_______ 18 x 16 x 17

Physical Limitations

Viewer Distance

The viewer distance is needed not only for determining display size, but it is also needed for calculating pixel density, which is a final image specification. The choice of viewer distance will be left to the discretion of the user of this document. Viewing distances should be chosen where vision is most effective or most comfortable. Leibowitz and Owens (1978), determined that the eye has a preferred focus distance, referred to as the "resting point of accommodation (RPA)". RPA varies between individuals, but with normal sight it generally lies between one and two meters (40 to 80 inches). This sets the range of image viewing distance that is most comfortable for human vision (Booth and Farrell, 1979).

What is the maximum distance of the viewer(s) to the display?

Please state in feet: ______________________

Viewer Distance

Display Size--
Unknown

UNKNOWN DISPLAY SIZE

If you said "unknown" to display size in the previous diagram, the display size will need to be determined through calculating the visual angle, through information obtained concerning the largest target size and viewing distance, and in specifying the number of users. The following table shows the optimum, preferred limits and acceptable limits pertaining to display size ratios to viewing distances and a variety of other factors to be considered in a visual display system.

FACTOR	OPTIMUM	PREFERRED LIMITS	ACCEPTABLE LIMITS
Ratio of $\frac{\text{viewing distance}}{\text{screen diagonal}}$	4	3-6	2-8
Angle off centerline	0 mrad (0°)	350 mrad (20°)	525 mrad (30°)
*Image luminance (no film in operating projector)	35 cd/m² (10 ft-L)	27-48 cd/m² (8-14 ft-L)	17-70 cd/m² (5-20 ft-L)
Luminance variation across screen (ratio of maximum to minimum luminance)	1	1 5	3 0
Luminance variation as a function of viewing location (ratio of maximum to minimum luminance)	1	2 0	4 0
Ratio of $\frac{\text{ambient light}}{\text{brightest part of image}}$	0	0 002-0 01	0 1 max**

*For still projections higher values may be used

**For presentations not involving gray scale or color (e g linedrawings ratio of 0 2 may be used

Group viewing of Optical Projection Displays (MIL-STD-1472c).

Several tables of display sizes will be presented to you in the final image descriptions. These tables incorporate the calculated visual angle, number of observers and viewing distance, and allow you to make a display size decision easily.

If there are known physical constraints that require the chosen display size to fit into a small area, please use the physical constraints information found in the next section to determine the appropriate display size.

Physical
Constraints

Sometimes the area allotted in the design of a system has been determined by engineering descriptions which are completed for an entire environment (such as a real-life simulator). A visual display panel, such as one that may be used in the modeling of a fighter aircraft, may be allotted only a five inch square surface area for visually displaying information. Obviously in a case such as this, a thirteen inch diagonal screen becomes unusable. If there are known physical constraints that require the chosen display size to fit into a small area, please choose from among the physical constraints categories shown below to determine the appropriate display size.

Please choose the category below that best describes the physical space limitation (in inches):

_______ 4 x 3 x 5 _______ 8 x 6 x 9
_______ 19 x 12 x 15 _______ 18 x 16 x 17

Physical Limitations

Number of Viewers

Although the taxonomy makes no suggestions on effective audience sizes for training, the number of viewers does make a difference when selecting a display size. As a general rule, the larger the number of viewers, the larger the necessary display size. The display size must increase as the number of viewers increase to accommodate those viewers seated in the rear and to the sides of the display area. In order to determine the final display size as an image specification, the maximum number of viewers for the display should be used.

What is the expected number of simultaneous users of the display?

_______ 1 _______ 2 - 3 _______ 4 - 8 _______ 9 - 15 _______ >15

Number of Viewers

Viewer Distance

Maximum viewer distance is a factor used to determine the appropriate display size, and is also needed for calculating pixel density, which is a final image specification. The choice of viewer distance will be left to the discretion of the user of this document. Viewing distances should be chosen where vision is most effective or most comfortable. Leibowitz and Owens (1978), determined that the eye has a preferred focus distance, referred to as the "resting point of accommodation (RPA)". RPA varies between individuals, but with normal sight it generally lies between one and two meters (40 to 80 inches). This sets the range of image viewing distance that is most comfortable for human vision (Booth and Farrell, 1979).

What is the maximum distance of the viewer(s) to the display?

Please state in feet: ____________________

Viewer Distance

Largest Target

The largest target size will be used in the final deterination of display size. The largest target size needed is the actual target size as it appears on the screen. Do not be concerned, at this point, with the visual arc subtended by the target.

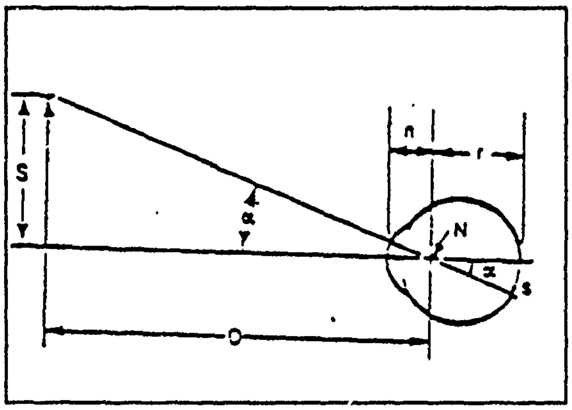
What is the largest target you wish to have fully displayed?

Please state in inches: ____________________

Largest Target Size

Visual Angle

The first step in the final determination of display size is the determination of the visual angle that will be subtended by the eye to the displayed image. A simple formula will be given below for calculating visual angle. The visual angle, along with the number of viewers and the viewing distance will be combined to determine display size in the final image specification for display size. The following figure provides the parameters involved in the calculation of visual angle:



S= target size; D= distance of target from nodal point of eye; N= nodal point; n= distance of nodal point from corneal surface; r= distance of nodal point from retinal surface; s= retinal extent; a= visual angle (Boff and Lincoln, 1988).

The visual angle needed is the visual angle of the target image, and not the entire display. The formula for visual angle (adopted from Van Cott and Kinkade, 1972, p. 46) follows:

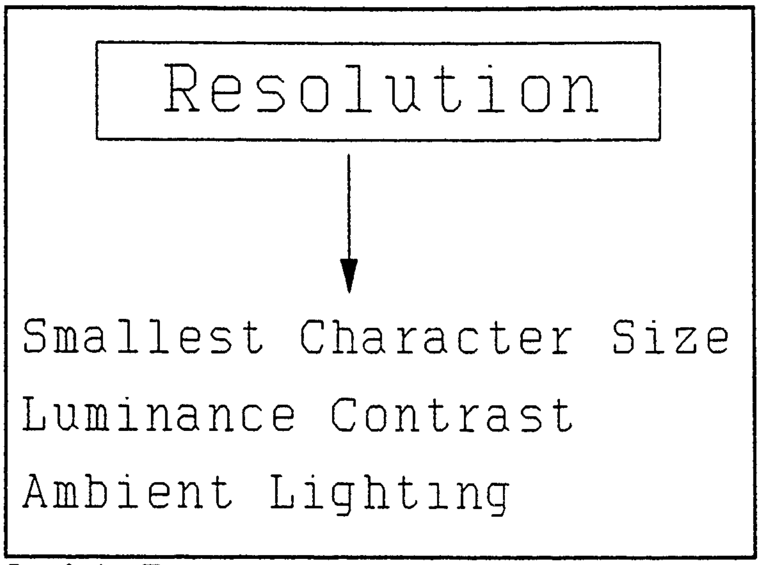
$$VA = \frac{(57.3)(12)(T)}{D}$$

where:
VA = visual angle (in degrees)
T = largest target size (in inches)
D = viewing distance (in feet)

Please record the visual angle as determined in the formula: ______________

Visual Angle

RESOLUTION

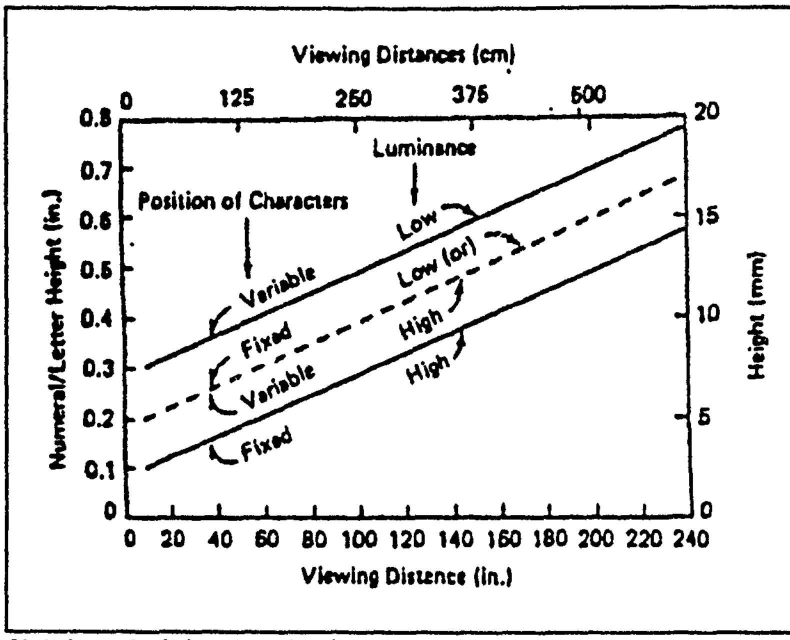


Resolution Tree

Resolution is a measure of the ability to delineate picture detail. Resolution in cathode ray tubes is usually expressed as the number of scan lines in the vertical dimension of the raster (i.e. the direction perpendicular to the scan lines). When speaking of CRT resolution, Booth and Farrell (1979) note that this type of displayed material is dependent upon the number of active scan lines in the display, the time allotted to write each line, and the bandwith of the system. A line of TV resolution is either the light or dark portion of a periodic target, as opposed to the designation of resolution as the number of line pairs (both the light and dark portions of a periodic target) used in optics. Two lines of TV resolution, then, are required to equal one line pair of optical resolution. Resolution of a visual display system will be calculated through information given concerning the smallest character size, luminance contrast and the ambient lighting condition.

Smallest Character Size

The smallest character size will correlate to the smallest height of a line of characters and will be used in the final determination of pixel density. The human eye is capable of identifying the letters of the alphabet if these letters subtend a visual angle of at least five minutes of arc (VanCott and Kincade, 1972). This five minutes of arc defines 20/20 vision as measured by the Snellen eye chart. When determining the smallest character size, the viewer distance and the instructional medium type should be kept in mind. At reading distances (approximately 28 inches), for printed material as well as CRT displays, the most common type size ranges from .09 of an inch to .11 of an inch (Sanders and McCormick, 1987). For reading characters at a distance, "it has been generally assumed that the legibility and readability are equal for various distances if the characters are increased for distance viewing so the visual angle subtended at the eye is the same" (Sanders and McCormick, 1987). The following figure depicts various acceptable heights of characters at various viewing distances and luminance levels.



Heights of alphanumeric characters for various viewing distances for fixed and variable positions of characters and for low and high levels of luminance. (Sanders and McCormick, 1987)

As shown in the above graph, some people will prefer to view characters at a distance closer than the reading distance of 28 inches. For CRT displays, a common viewing distance is closer to 18 inches rather than 28 inches. No matter what the viewer distance will be, the size of the smallest character can still be determined through using an acceptable visual angle as your guideline. "The characters should be of a size to subtend a minimum visual angle of about 12 minutes of arc, but with larger configurations if any special considerations apply (such as time constraints, criticalness, poor viewing conditions, etc.)" (Sanders and McCormick, 1987). The smallest character size will be determined by choosing the expected task of the viewer of this display system.

Which type of task best describes the main use of this display system?

_______ Accurate legibility of single characters (Threshold only)
_______ Comfortable reading (Threshold only)
_______ Combination of both of the above (Preferred size)

Smallest Target Determination

Luminance Contrast

To be visible, information displayed must have either a higher or lower luminance than the surrounding areas (Salvendy, 1987). This difference in luminance levels is the luminance contrast. According to Grether and Baker (1972) the luminance contrast is frequently called brightness contrast or simply contrast, and refers to the difference in luminance of the features of the target from its background luminance. This difference is usually stated as a ratio (contrast ratio). The minimum contrast ratio acceptable for general display conditions is within the range of 10:1 to 18:1 with a 10:1 ratio being a generally accepted industrial standard for display design (Salvendy, 1987). The 10:1 ratio is reported by Salvendy (1987) to be a good, valid choice for character sizes between 16 and

25 arcminutes. (For a point of reference, Boff and Lincoln (1988) calculated the size of alphanumeric characters on a CRT screen when viewed at a distance of 20 inches to be 17 arcminutes.) Of course, the smaller the size of the character the higher the contrast ratio should be.

It may be important to note that there is a difference between static and dynamic perceptions of contrast threshold. According to Boff and Lincoln (1988), contrast threshold for moving targets varies little as target distance from fixation increases; however, the contrast required to detect a stationary target increases the further the target is from fixation. As a general rule, as background luminance increases, the minimum contrast needed to detect a target's presence or to judge its detail decreases. The level of display luminance is dependent on the type of task to be completed, therefore display luminance will be translated from the choice made between various taskings.

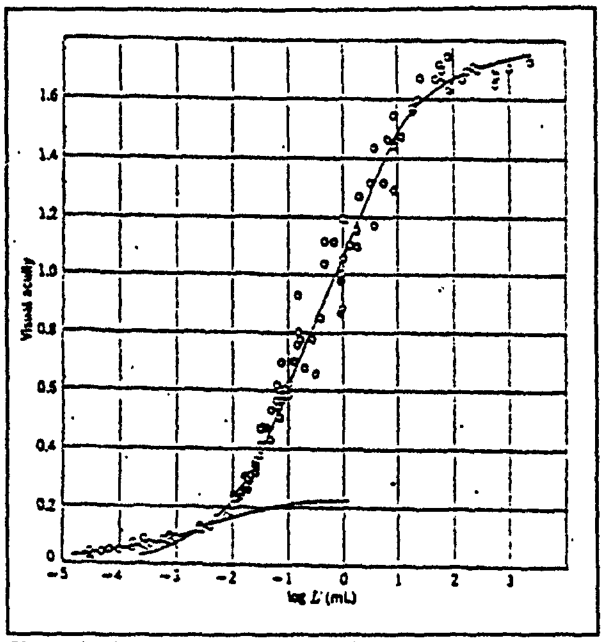
Please choose the description below that best describes the type of task determined for this display system:

_______ Casual examination to locate general features
_______ Performing normal interpretation functions
_______ Extensive, detailed examination of the imagery

Display Luminance Determination

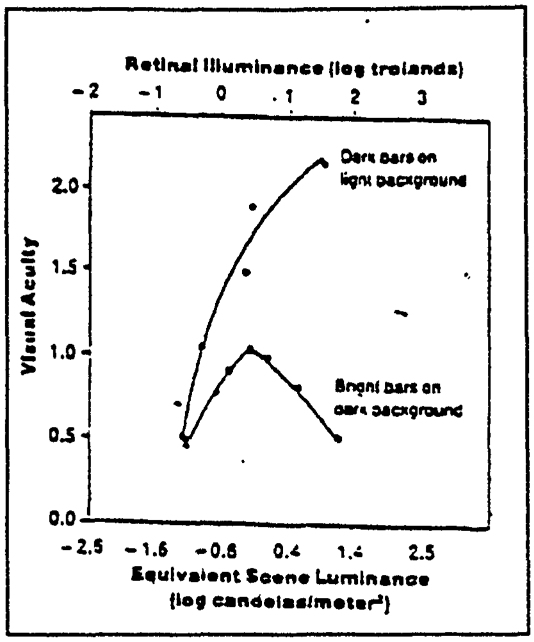
Ambient Illumination

Ambient illumination includes all sources of illumination except those used to display imagery or signals (Farrell and Booth, 1984). If the ambient lighting condition will be at a low level, character luminance must be reduced to maintain the viewer's dark adaptation, and at a high level of ambient illumination, character luminance should be significantly increased to compensate for an apparent color fading or "washout" that can occur due to the reduction of the symbol-to-background contrast (Geldard, 1972). It is assumed the observers will be adapted to the surrounding light. As added information, one should realize that a dark adapted observer takes more time to adapt to a light source than a light adapted observer trying to adapt to darkness. A relationship exists between the level of illumination and visual acuity. The following figure depicts the relationship between visual acuity and illumination.



Konig's data for the relation between visual acuity and illumination, as replotted by Hecht (1934). The shallow curve for lower limb of the data is an equation for rods, whereas the upper curve is for cones.

This relationship will determine if a given illumination level is acceptable to produce visually legible characters. The choice of which background illumination level to use affects acuity of the observer and the level of lumination necessary to produce legible images. The following figure represents visual acuity as a function of intensity for parallel bar targets.



Visual acuity as a function of intensity for parallel bar targets. Acuity is equal to 1 divided by resolution threshold in min of arc visual angle; normal acuity is = 1.0 (i.e., threshold of 1 min arc) (Bartley, 1941 and Wilcox, 1932).

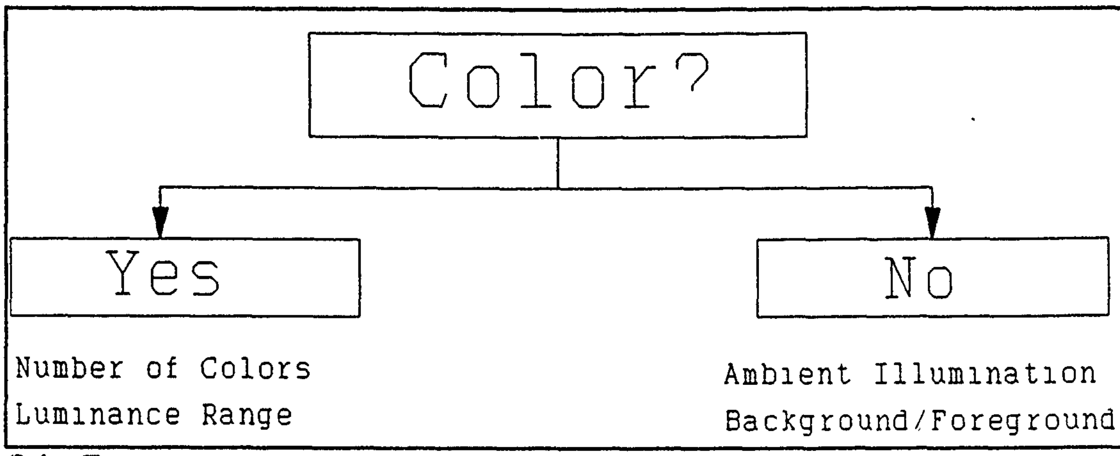
The ambient lighting response will be used in the final calculation of pixel density and will be based on a choice from four common illumination levels.

What will be the predominant ambient lighting condition for viewing the display?

_______ Theater lighting: 0.07 to 0.34 cd/m^2
_______ Low level office: 30 cd/m^2
_______ Routine office : 300 cd/m^2
_______ Daylight : 1,000 cd/m^2

Ambient Illumination

COLOR



Color Tree

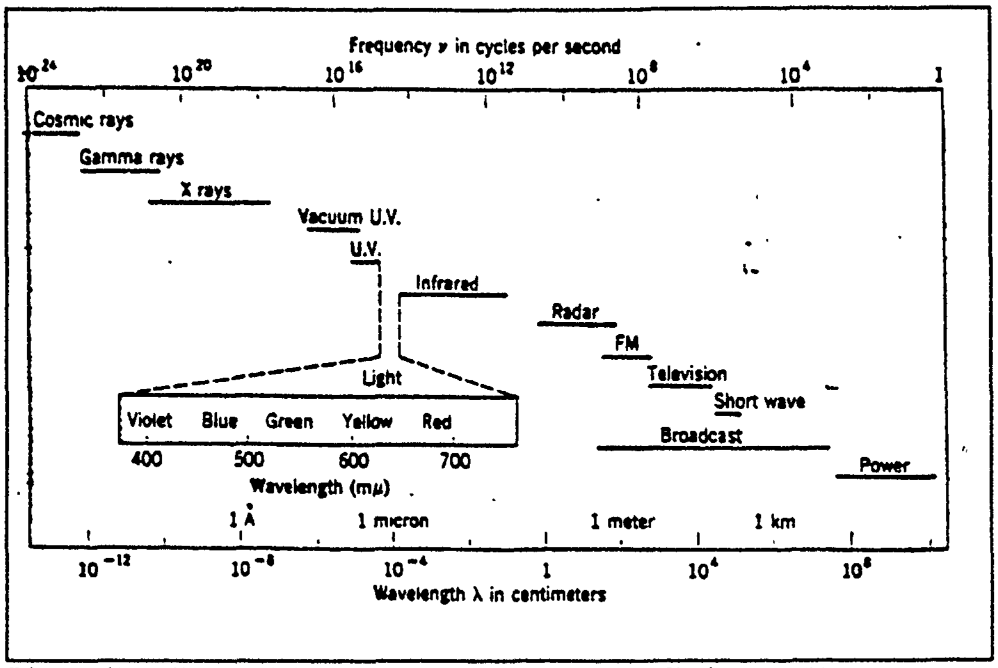
COLOR

Color--
Yes

If you answered "yes" to color, a color system is required, and you will need to choose the number of colors as well as the luminance range to be used in the final image descriptions. Normally, color is not a real requirement. Color can be perceived as a nicety except where ease of identification is required. To determine final descriptions, the number of colors needed as well as the luminance range will need to be obtained. The luminance range will be based on information given in the resolution determination of luminance contrast, and will not be repeated here. Given the availability of color displays and preferences and color, the following recommendations are made:

Number of
Colors

Limits exist to the number of reasonable, codeable colors available. The preferred limit of different colors (hues) is nine (Sanders and McCormick, 1987). These hues fall within the visible spectrum of human vision as shown in the figure below.



The Radiant Energy (electromagnetic) Spectrum (McKinley, 1947).

The following list of the number of colors available is a guideline based on current computerized images. This is not an exact list, but the chosen number will be considered as a final specification.

Please choose the number of colors for this system:

_______ 4 _______ 8 _______ 16 _______ 32

_______ 64 _______ 128 _______>128

Number of Colors

Adaptation of observers. One important note is that it is assumed the observers will be adapted to the surrounding light. As added information, one should realize that a dark adapted observer takes less time to adapt to a light source than a light adapted observer trying to adapt to darkness.

MONOCHROME

Color--
No

If you answered "no" to color, a monochrome system has been chosen. A monochrome display consists of a foreground color and a background color only. Normally, the difference between the foreground and background is basically described as dark and light (i.e. a light color foreground on a dark color background or vice-versa). Because of the limitation of a monochrome system, the ambient illumination along with the luminance contrast become important considerations. The choice of either a light foreground on a dark background or a dark foreground on a light background will also affect observer variables and therefore should be considered.

Ambient
Illumination

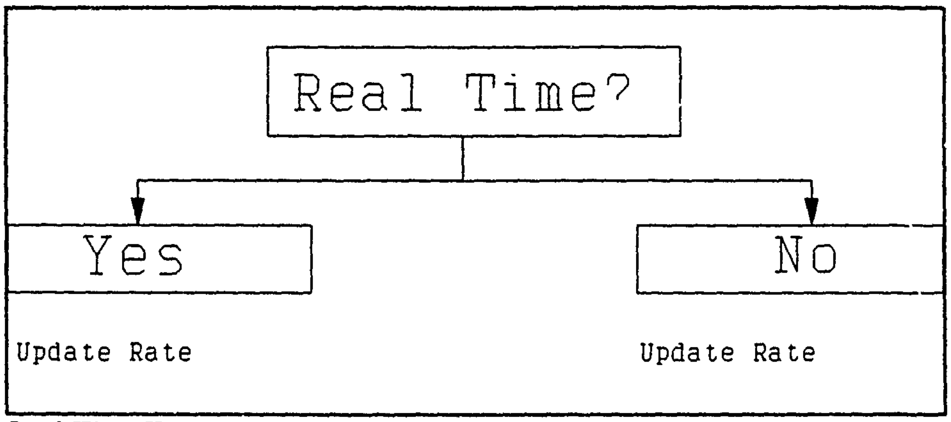
Ambient illumination was discussed in the previous section, *Resolution*. The ambient illumination was determined by one question concerning the expected lighting condition where the display system will be housed. If the response needs to be modified, please return to that section to make the modification. The information will not be repeated here as no new information pertaining to a monochrome system should affect the response given previously.

Background/
Foreground

The decision as to which orientation is best for this display system is left up to the user. This category will not be used in the final image specification as most computerized images allow the user to change the orientation of the foreground and background. Other systems will normally show the background and foreground in an expected manner; i.e. a monochrome (black and white) filmstrip will show a positive image (those things in the environment that are light will remain so, and those things in the environment that are dark will normally be displayed as such) versus a negative image (like a negative of a photograph).

If a decision must be made as to the orientation of the background and foreground of the display system then the following information should be considered: for an alphanumeric display system, the stroke width of the characters will an important characteristic. (Stroke width is the ratio of the thickness of the stroke to the height of the alphanumeric image.) When deciding upon a negative or positive orientation for an alphanumeric display a phenomenon called irradiation needs to be discussed. According to Sanders and McCormick (1987): "*irradiation* causes white features on a black background to appear to 'spread' into adjacent dark areas, but the reverse is not true. Thus, in general, black-on-white letters should be thicker (have lower ratios) than white-on-black ones."

REAL TIME



Real Time Tree

For dynamic displays
Real Time--Yes

The use of the term "real time" in the generation of images is an artificial convenience. Imaging systems present information in a discontinuous fashion. Complete images are sent to the screen and then persist for short periods of time. Systems termed "real time" operate at speeds great enough such that the human visual system does not perceive the discontinuous signals sent by the imaging system (Vince, 1984 and Rogers & Earnshaw, 1987). Individual frames or pictures are strung together and then presented at speeds fast enough such that the images appear to move smoothly. The number of times that an image is sent to the screen for portrayal is termed "update rate" (Rogers and Earnshaw, 1987). The greater number of updates in the presentation, the more continuous the image appears to the human visual system.

The updating of scenes is a characteristic of all image generation systems. Photographs can be considered to have an update rate of one frame. Obviously one photograph is insufficient to portray image movement. But, by placing many individual photographs together and imaging them sequentially, movement can be portrayed. Movies work in this fashion (Vince, 1984). The portrayal of continuous movement is the basis for the term "real time." Images that move in real time, generated in real time, move smoothly across the screen. Real time systems are also considered to be interactive (Freeman, 1980). The motion rates and directions should be capable of being changed through dynamic user interactions. If the system can adjust and make these changes such that the image appears to change instantaneously with user commands, then this system is termed "real time." For example, if in an interactive driving simulator, a subject turns his steering wheel to make a left hand turn, and the system continues to represent his movement in a forward direction, even for 500 milliseconds, then the system can not be denoted as "real time." The system is not capable of updating the displayed image with new information quickly enough to respond to the subjects inputs.

For images to transition smoothly across the screen and to have users responses seemingly portrayed instantaneously, the system must have update rates of equal to or greater than thirty frames per second (fps). Systems that operate at slower update rates will appear discontinuous at times (Vince, 1984 and Castleman, 1979).

The update rate of a system is intimately tied with the system processing speed and the complexity of the scene (Freeman, 1980). A scene is either generated through algorithms which determine image portrayal surfaces or the images are accessed from some storage medium. With either method, the correct sequences of images and the correct viewing angle of the image must be portrayed. Complex images require more data to be organized prior to presentation. The speed at which a system accesses or generates these images is critical to the update rate. Systems that cannot generate the required thirty fps while portraying view point changes, can not update the information quickly enough for instantaneous user interaction or continuous motion to be perceived.

When asked if the system requires real time portrayal of user interactions an answer of yes, immediately indicates that the generation system must be capable of presenting the image at rates greater than thirty fps. Portrayal of user interaction in "real time" requires that the processing speeds of the system must be fast enough to depict image changes as they occur.

For static images--
Real Time--No

When a static image is desired, real time processing is not required, and an update rate of 10 fps is considered sufficient for any user interactions.

The final image specification for this section will come directly from the question below. A yes or no answer will directly correlate with an update rate as an image specification.

Does the system require the images to be displayed in a real time manner ?.

_______ Yes _______ No

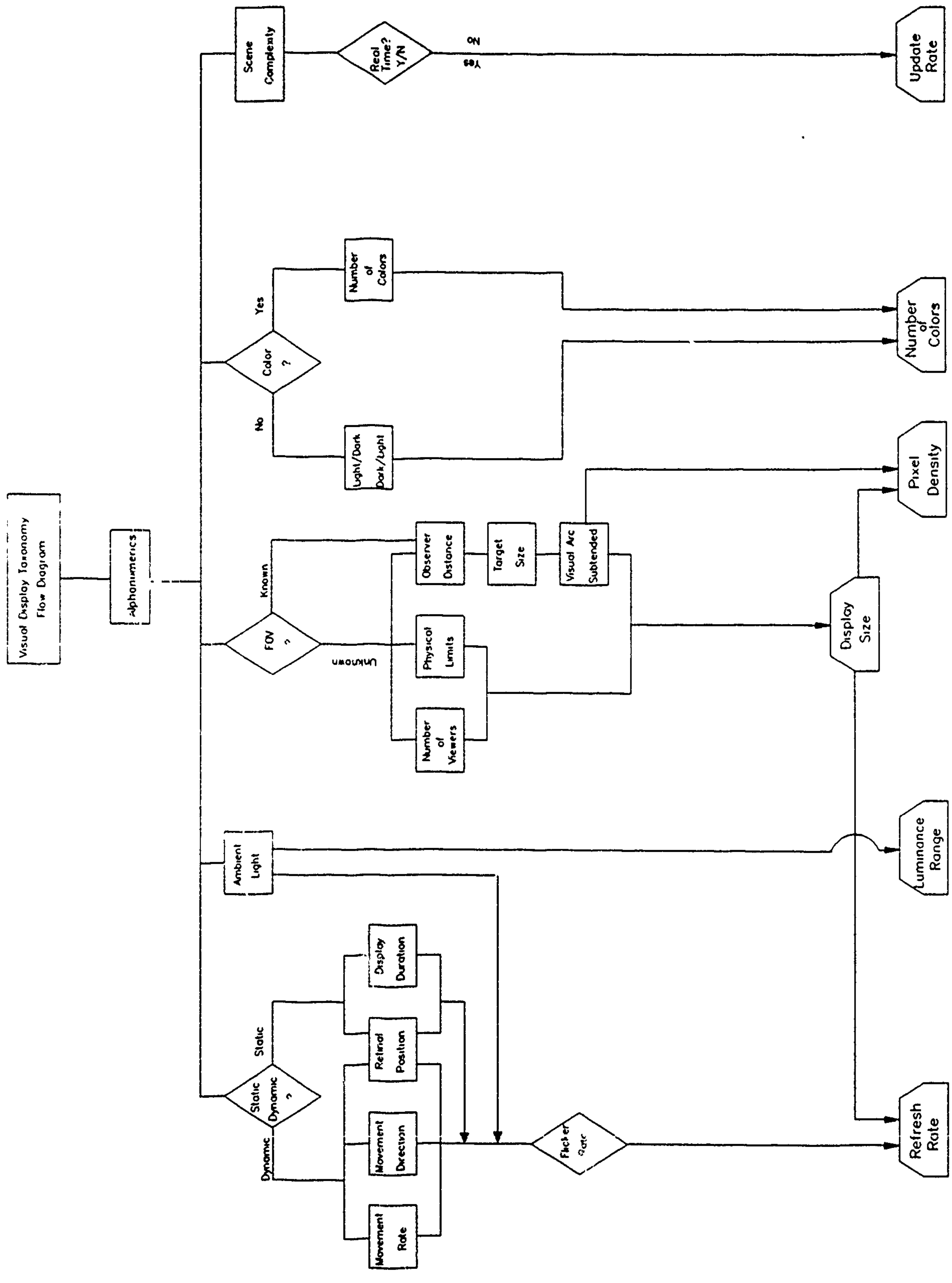
Update Rate Determination

Final Image Descriptions for an Alphanumeric Presentation

The following section leads through the necessary computations to produce the final image descriptions needed for an alphanumeric display. This section will contain six subsections as final image descriptions: refresh rate, display size, luminance range and contrast, pixel density, number of colors, and update rate. At this point in time, these six descriptions will provide enough information for the user of this taxonomy to communicate with engineers and other designers of visual display systems.

The decision flow diagram for alphanumerics (found on the following page) should prove to be a helpful visual aid as you work through this section. The six final image descriptions can be found at the bottom of the flow diagram. These description names will be the titles of each of the subsections to follow in the text. If you begin with one of the image description boxes and follow the flow "backward" you should be able to discern the path chosen for the subsection you're working through. Some subsections may not contain all the boxes in the flow; these boxes will not have a corresponding shaded box in the *Initial Considerations*, and therefore should pose no problem in calculations.

Before beginning with this section, all questions (in shaded boxes) from the *Initial Considerations--Alphanumerics* section should be complete with responses. These responses should be in front of you as you work through this section.



Visual Display Taxonomy Flow Diagram
Alphanumerics
Scene Complexity
Real Time? Y/N
No
Yes
Update Rate
Color ?
Yes
No
Number of Colors
Light/Dark Dark/Light
Number of Colors
FOV ?
Known
Unknown
Observer Distance
Target Size
Visual Arc Subtended
Pixel Density
Physical Limits
Number of Viewers
Display Size
Ambient Light
Luminance Range
Static Dynamic ?
Static
Dynamic
Display Duration
Retinal Position
Movement Direction
Movement Rate
Flicker
Refresh Rate

REFRESH RATE

Refresh rate is determined using information obtained concerning the retinal position, minimum display duration, ambient light condition, and the flicker criticality chosen. The determination of refresh rate is critical to the system in that higher refresh rates appear to flicker (turn on and off) less than those systems with lower refresh rates (this assumes the display system uses a CRT or like display which turns on and off regularly). Thus, the main focus for determination of refresh rates is in the elimination of flicker from the display environment. Critical flicker frequency (CFF) is defined as the lowest frequency at which a light will be perceived as anything but a steady light. It is difficult to determine the CFF for all conditions that the display will be viewed under. General guidelines are available, however, and will be applied in the final specification. "The display should be 'flicker free' for at least 90 percent of a sample of the user population under conditions representative of actual use" (ANSI/HFS).

The following boxes contain information derived from the shaded boxes from *Alphanumerics* along with refresh rates (in bold) measured in hertz (hz) levels:

The object will fall on the observers' retina:

--at fixation position	= **20 Hz**
--less than 5° from fovea	= **30 Hz**
--between 5° and 30° from fovea	= **45 Hz**
--greater than 30° from fovea	= **60 Hz**

Retinal Position

The chosen minimum display duration is:

--100 msec or more	= **10 Hz**	--25 msec	= **40 Hz**
--80 msec	= **15 Hz**	--20 msec	= **50 Hz**
--50 msec	= **20 Hz**	--15 msec	= **60 Hz**
--33 msec	= **30 Hz**		

Minimum Display Duration

The rate of motion across the screen (per second) will be

--low = 15 Hz
--medium = 30 Hz
--high = 60 Hz

Movement Rate

The predominant ambient illumination for viewing the display is:

--Theater lighting = 10 Hz
--Low level office lighting = 30 Hz
--Routine office lighting = 50 Hz
--Daylight = 80 Hz

Ambient Illumination

A refresh rate should now be selected for each of the above variables. Chances are the hertz levels are not all the same, but a single value is needed for refresh rate. The highest level, lowest level, or an average of levels will be used depending upon the flicker criticality determination.

Removal of flicker from the display is:

--Critical	: Choose the largest hertz value for refresh rate
--Important	: Add all hertz levels. If minimum display duration is less than 100 msec then divide by four. If minimum display duration is 100 msec or greater, subtract 10, and divide by three
--Non-critical	: Choose the smallest hertz value for refresh rate

Flicker Criticality

Flicker criticality was the final determinant for refresh rate, and therefore is an important consideration. Other variables can affect refresh rates by affecting critical flicker frequency. For instance, the type of phosphors used in a CRT display can require different refresh rates to maintain similar CFF thresholds. "The relative amount of flicker is related to the persistence characteristics of the phosphor" (Boff, 1988). Display luminance can also affect flicker, thereby affecting refresh rates: "Flicker in CRTs cannot be noticed at a 60 hz refresh rate unless display luminance exceeds 620 cd/m^2" (Boff, 1988). The observer should also be considered fully adapted to the lighting environment. Transient adaptation of the viewer may allow flicker to be perceived, whereas at final adaptation levels the image will not appear to flicker.

DISPLAY SIZE

Display size can be determined in one of three ways: first, the user can have a predetermined display size, small, physically limiting dimensions may be present, or the display size can be calculated using the anticipated viewing distance, the size of the largest character, and the expected number of simultaneous users of the display. If the user has a predetermined display size, that size should be used, and the rest of this section can be overlooked. If the visual display system must be housed in an area less than 13 inches (measured diagonally) use the following information to determine the field of view:

The best description of the physical limitation is:

	Field of View
-- 4"x 3"x 5"	= 5"
-- 8"x 6"x 9"	= 9"
--19"x12"x15"	= 15"
--18"x16"x17"	= 19"

Physical Limitations

If the display size is unknown, please have ready the visual angle that was calculated in the *Initial Considerations* section. The remainder of the shaded boxes from the *Initial Considerations* may be ignored; they were used in the determination of the visual angle.

The calculated visual angle for this system is ________________.

Visual Angle

In order to simplify the determination of a display size, use the following tables to "look-up" an appropriate display size. The tables are based on the responses given for visual angle, the expected number of viewers, and the maximum distance of the viewer(s) from the display. The tables can be used to determine the field of view required by this display system application. It should be noted, however, that these recommendations should not be considered as absolute values. There are no research findings linking human performance to display size requirements. The only findings indicate that larger fields of view can inhibit performance.

Viewing Distance (feet)	Visual Angle (Degrees) 5	10	20	50	120
1.5	13	17	25	48	126
3	17	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is one. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

Viewing Distance (feet)	Visual Angle (Degrees) 5	10	20	50	120
1.5	15	17	25	48	126
3	17	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is between two and three. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

	Visual Angle (Degrees)				
Viewing Distance (feet)	5	10	20	50	120
1.5	17	19	25	48	126
3	19	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is between four and eight. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

	Visual Angle (Degrees)				
Viewing Distance (feet)	5	10	20	50	120
1 5	19	21	25	48	126
3	21	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is between nine and fifteen. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

Viewing Distance (feet)	Visual Angle (Degrees) 5	10	20	50	120
1.5	19	25	48	48	126
3	25	48	48	126	
7	48	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is greater then fifteen. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

PIXEL DENSITY

Legibility is the rapid identification of single characters that may be presented in a non-contextual format. The threshold height for rapid and accurate legibility of single characters is i the range of 11 to 12 minutes of arc, depending on resolution and character definitions. The threshold height for comfortable reading during a legibility task is in the range of 16 to 18 minutes of arc. However, the preferred character size of printed material, for both readability and legibility tasks is in the range of 20 to 22 minutes of arc.

Readability is the ability to recognize the form of a word or group of words for contextual purposes. Character heights that are large (more than 24 minutes of arc) may inhibit the reading process by reducing the number of character positions that may be foveally viewed per fixation. The generally preferred character height for printed material is in the range of 20 to 22 minutes of arc. Thus, research indicates that a character size that is 40 to 50 percent larger than threshold character size (for a given level of performance) results in comfortable reading of text (Haubner and Kokoxchka, 1983: Rogers and Futmann, 1983).

A 7x9 (width-to-height) character matrix should be the minimum matrix used for tasks that require continuous reading for context, or when individual alphabetic character legibility is important, such as proofreading. Stroke width should be greater than 1/12 of the character height. A stroke width may be more than one pixel wide. Once the character is well above the minimum size, contrast, and luminance level, the stroke width of a character is not critical for performance.

Before pixel density can be determined, the presentation size of the alphanumeric characters needs to be chosen. You also need to have the viewing distance (recorded in the *Initial Considerations* section) and the display size (from the previous *Final Image Description* section) in front of you at this time.

The task that best describes the main use of this display system is (numbers are minutes of arc):

--Accurate legibility of single characters (Threshold only)	: **11 to 12**
--Comfortable reading (Threshold only)	: **16 to 18**
--Combination of both (Preferred size)	: **20 to 22**

Smallest Character Size

Please state the viewing distance (in feet) ______________

Viewing Distance

The display size for this system is __________

Display Size

Once the answers to these questions have been chosen, use the following tables to find the appropriate pixel density. Find the graph that represents the size of characters you chose; locate the viewing distance, and display size. The required pixel density will be found in the table containing the given information.

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 5	12	18	22
1.5	640x480	512x512	640x200	320x200
3	512x512	640x200	320x200	
16	640x200	320x200		
33	320x200			

Pixel Density Recommendations (Alphanumerics) for display size *__Diagonals of between 13 and 15 inches__*. *Recommendations are based on character size in minutes of arc, viewing distance, and display size diagonal.*

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 5	12	18	22
1.5	640x480	512x512	640x200	640x200
3	512x512	640x200	640x200	
16	640x200	640x200		
33	640x200			

Pixel Density Recommendations (Alphanumerics) for display size *__Diagonals of 17 inches__*. *Recommendations are based on character size in minutes of arc, viewing distance, and display size diagonal.*

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 5	12	18	22
1.5	1024x1024	640x480	512x512	640x200
3	640x480	512x512	640x200	
16	512x512	640x200		
33	640x200			

Pixel Density Recommendations (Alphanumerics) for display size Diagonals of 25 inches. Recommendations are based on character size in minutes of arc, viewing distance, and display size diagonal.

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 5	12	18	22
1.5	1024x1024	640x640	640x480	512x512
3	640x640	640x480	512x512	
16	640x480	512x512		
33	512x512			

Pixel Density Recommendations (Alphanumerics) for display size Diagonals of 48 inches. Recommendations are based on character size in minutes of arc, viewing distance, and display size diagonal.

		Visual Angle (Minutes of Arc)			
		5	12	18	22
Viewing Distance (feet)	1.5	2048x2048	1024x1024	640x640	512x512
	3	1024x1024	640x640	512x512	
	16	640x640	512x512		
	33	512x512			

Pixel Density Recommendations (Alphanumerics) for display size <u>Diagonals of 126 inches</u>. Recommendations are based on character size in minutes of arc, viewing distance, and display size diagonals.

LUMINANCE RANGE AND CONTRAST

In the *Initial Considerations* section, luminance constrast and ambient illumination were discussed in detail. This information should be used for background knowledge for terminology when speaking with the system designer. For the final image description of the luminance range, however, the only determinant in the flow diagram is the ambient lighting condition. The system designer should be able to use this information to determine what type of luminance contrast will be needed for your specific system.

The ambient illumination for this system will be:
-- 0.07 to 0.34 cd/m^2
-- 30 cd/m^2
-- 300 cd/m^2
--1,000 cd/m^2

Ambient Illumination

NUMBER OF COLORS

The number of colors is determined by the user of this document. In the *Alphanumerics* section, a choice was given between a monochrome system and a color system. Choices were also presented, for a color system, as to how many colors were preferred for this display system. The responses to these choices directly correspond to final image descriptions, but will be repeated here for your convenience:

Please choose the number of colors for this system:

_______ 2 (monochrome)

_______ 4 _______ 8 _______ 16 _______ 32

_______ 64 _______ 128 _______ >128

Number of Colors

UPDATE RATE

Update rate is the number of times that the system updates screen information. Update rates in the low range are sufficient for most applications. In the *Initial Considerations* section, update rate was discussed as a function of the need for a real time system. Normally, real time applications are not needed for displaying alphanumeric characters, and consequently, the update rate of the system is not critical to presentation. Thus, low update rates in the range of 5 hz are acceptable for most applications. Faster update rates may be required for special applications. This would need to be discussed further with the system designer.

GRAPHICS

You have chosen to display either two-dimensional graphics, three-dimensional graphics, or three-dimensional scenes as your most complex display image. Two dimensional and three-dimensional graphics include line figures, symbols, and basic geometric shapes with no depth cues. The difference between the two-dimensional image and the three-dimensional image is the embellishment of realism of the added third dimension. When special effects and extra details are added to the three-dimensional image, a "real-life" scene may be acheived.

There are several ways to display a three-dimensional image. For example, the hologram is an actual three-dimensional display derived from a split laser beam. Beyond the hologram, three-dimensional images can be created on a two-dimensional display system through illusion. One way to create the three-dimensional illusion is to use binocular disparity. Binocular disparity is the method used in stereoscopic displays. This method involves two slightly different views of the same object or scene viewed together through a stereoscopic device, such as using a child's stereoscope or using "3-D glasses" to view a "3-D movie." In order to create a three-dimensional image on a two-dimensional display system, such as the canvas of an artist or a CRT, some "tricks" must be employed. The following list of definitions are considered to be techniques to accomplish the effect of a three-dimensional image when using a two-dimensional display system.

FOR A STATIC DISPLAY:

Linear Perspective:	Depth illusion is created with linear perspective as parallel lines converge in the "distance."
Occulting:	The effect of "near" objects overlapping "far" objects. This also refers to the front of an object overlapping the back of an object.

FOR A DYNAMIC DISPLAY:

Motion Parallax:	This is the dynamic version of linear perspective defined previously. Motion parallax creates the "out of window" illusion whereby objects that are close to the field of view move by quickly, and objects in the distance of the field of view move by slowly.
Deletion and Accretion	This is the dynamic version of occulting. Deletion occurs when an object in the background appears to be covered by an object in the foreground as movement of the observer occurs. Accretion occurs when an object in the background appears to be uncovered by an object in the foreground as movement of the observer occurs.

FURTHER ENHANCEMENTS FOR STATIC AND DYNAMIC DISPLAYS:

Size in the FOV	Larger objects in a display appear to be closer than smaller objects.
Height in the FOV	Objects that are displayed higher appear to be in the distance as opposed to objects that are displayed lower in the field of view.
Atmospheric clues	The atmosphere tends to make objects look fuzzy or blurry in the distance. This fuzziness or blurriness increases with atmospheric haze or fog or other weather conditions. An illusion of the atmosphere can be transposed to help create the three-dimensional image.

The following prioritized list (from most to least powerful) contains special effects that are used in conjunction with the definitions above to facilitate scene quality. In general, the more tools incorporated into the system, the better the scene quality produced, and the greater the burden on system speed.

Shading. The use of shading is a powerful tool in creating a scene on a display system. Shading facilitates the viewer in perceiving the three-dimensional characteristics of a display by enhancing depth cues on a discontinuous surface. The appropriate use of gradients of surface shading can also provide cues as to the shape of objects. Illumination from a single light source will fall on a three-dimensional object in a consistent pattern. Generally, the surface of an object nearest the light source is the brightest. As the surface recedes from the light, it appears less bright and more darkly shadowed. Since those surfaces closest to the light source receive the most illumination, the shape of the object has an effect on the pattern of light and dark areas produced. Schiffman, 1982)

Shadows. The human eye perceives shadows based on several cues. For instance, the outer edge of a shadow (termed the penumbra) is fuzzy, not distinct. When a shadow is traced so as to make a dark border around the shadow, the shadow becomes an image in and of itself, no longer created by the object it shadows. When a shadow is illustrated on a display, normally at least a part of the object casting the shadow is seen. In this way, we assume the darker area created is a shadow, and not another part of the display. We also make distinctions between an illumination edge (an edge or contour in which the illumination on a surface changes) and a reflectance edge (an edge in which the reflectance of a surface changes). (Goldstein, 1989)

Weather effects. Sunny skies, rain, fog, haze, snow, hail, lightening, etc. are important environmental characteristics in producing a realistic outdoor scene.

Background. Background detail in the three-dimensional scene creates a more realistic perception of the displayed scene. For example, man made objects such as roads, buildings, cars, etc, as well as naturally occurring objects such as lakes, trees, hills, etc.

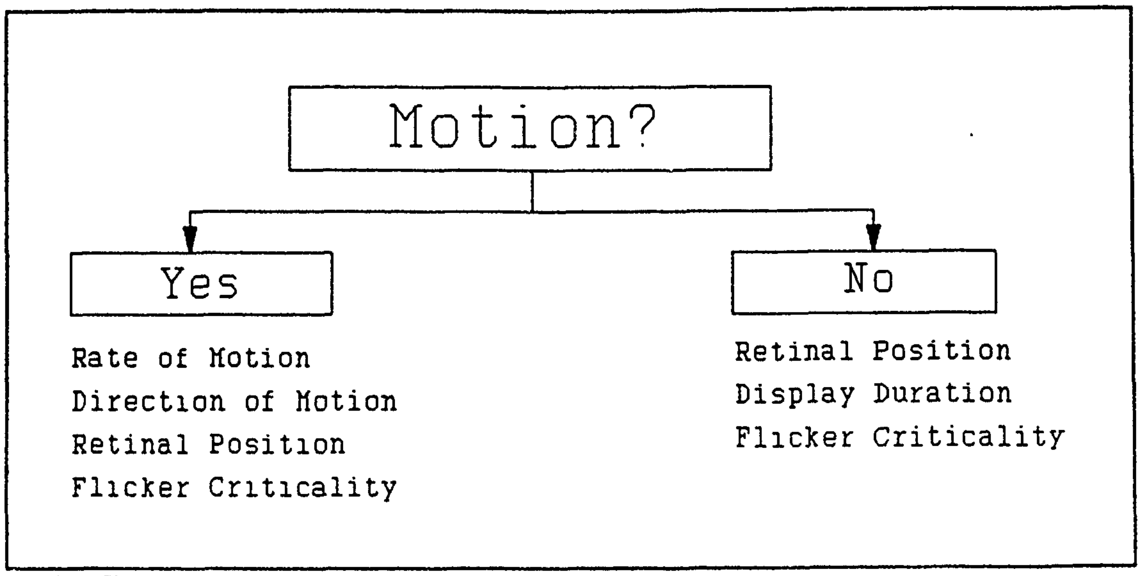
Movement of objects. The movement of objects in a three-dimensional scene helps to create a more realistic display.

How to use the Initial Considerations Section of this Taxonomy

The following section contains only those elements that are essential in defining a visual display system designed for graphical images. At the beginning of each subsection you will find a simple tree diagram of the initial requirement. This diagram will include the root (upper most box) which is the general area of concern. From the root, either a single path may be followed or a decision will need to be made between two broad elements. Following each of these branches will be a list of specific topics that choices will be made from.

Following each diagram will be background information, explanations, and definitions concerning the topic area. This information may be helpful in calculating the needed information described in the diagram. At the end of each subsection, a specific question will be asked. These questions will be found in shaded boxes, and they correlate directly to the final image specifications. It is important to have an answer for each question in order to accurately transfer needed information to the final image specifications.

Static versus Dynamic Display



Motion Tree

DYNAMIC DISPLAY

Motion-- YES

If you answered "yes" to motion, then you have chosen a dynamic display system. The following information will guide you through the constraints and factors of a dynamic visual display system.

According to Sanders and McCormick (1987) dynamic information is information that continually changes or is subject to change. Some example of dynamic information include traffic lights, speedometers, and radar displays. The intent of the dynamic visual display in this section is to create motion of the two-dimensional or three-dimensional image. The constraints to be used in determining the dynamic display characteristics are: (1) the rate of motion of the image across the screen, (2) the direction of the motion, (3) retinal position of the observer(s), and a (4) flicker criticality level. Once again, the responses obtained from this section correlate to the final image specifications and relationships to system design.

Rate of Motion

Rate of motion can be defined as the rate of speed that an object moves across the screen. This rate needs to be stated in degrees per second. The following table can be utilized to make conversions between miles per hour (or feet per second) and degrees per second.

Miles per Hour	Feet per Second	Degrees and Seconds									
100	146	164° 24'	149° 22'	135° 20'	122° 34'	111° 24'	101° 10'	92° 24'	84° 46'	78° 6'	72° 16'
80	118	160° 46'	142° 34'	128° 6'	111° 4'	99° 26'	89° 2'	80° 16'	72° 50'	68° 30'	61° 6'
70	102	157° 10'	136° 24'	119° 6'	103° 8'	91° 8'	80° 44'	72° 10'	65° 2'	59° 6'	54° 4'
60	88	154° 24'	131° 8'	111° 26'	95° 28'	82° 42'	72° 32'	64° 18'	57° 38'	52° 8'	47° 30'
50	74	149° 6'	123° 14'	101° 18'	85° 34'	72° 62'	63° 20'	55° 44'	49° 40'	44° 42'	40° 38'
40	58	141° 18'	110° 50'	88° 4'	71° 14'	60° 14'	51° 36'	45° 2'	39° 52'	35° 44'	32° 22'
30	44	131° 8'	95° 28'	72° 32'	57° 38'	47° 30'	40° 18'	34° 54'	30° 46'	27° 30'	24° 50'
20	29	110° 50'	71° 44'	51° 36'	39° 12'	32° 22'	27° 12'	23° 24'	20° 34'	18° 18'	16° 32'
15	22	95° 28'	57° 38'	40° 18'	30° 46'	24° 30'	20° 48'	17° 52'	15° 40'	14°	[illegible] 38'
10	15	73° 6'	41° 8'	28° 6'	21° 16'	17° 4'	14° 16'	12° 34'	10° 44'	9° 32'	8° 36'
8	12	61° 56'	33° 24'	22° 38'	17° 4'	13° 42'	11° 26'	9° 48'	8° 36'	7° 38'	6° 54'
5	7	38° 36'	19° 12'	13° 20'	10°	8° 2'	6° 42'	5° 50'	5° 2'	4° 28'	4° 2'
2	3	17° 4'	8° 36'	6° 4'	4° 18'	3° 26'	2° 52'	2° 28'	2° 10'	1° 56'	1° 44'
		10	20	30	40	50	60	70	80	90	100

Angular Speeds of Objects along a Path of Travel for Various Speeds and Distances (Salvendy, 1987).

Movement rates of less than 40 degrees per second will retain image visibility for identifying images. The eye will be able to track motion smoothly, at least in the horizontal direction, up to velocities of about 30 degrees per second (Farrell and Booth, 1984). According to Boff and Lincoln (1988), the dynamic visual acuity (visual resolution of a moving target) decreases as the angular velocity between a target and an observer increases; regardless of whether the target or the observer is moving. In other words: as the rate of motion increases, the rate of visual acuity (and therefore perceived resolution) decreases. One way to increase dynamic visual acuity is to increase the illumination as the angular velocity is increased (Boff and Lincoln, 1988).

According to Farrell and Booth (1984), one effect of moderate velocities of image motion on the viewer is to limit the time he can spend looking for a target. For example, with an image velocity of 20 degrees per second and an image field of 40 degrees, a single point on the image will be visible no longer than two seconds. Assuming each eye fixation lasts an average of 0.4 seconds, the observer is allowed only 5 fixations, in this example, to cover the entire image field.

Also according to Farrell and Booth (1984), image velocities of two to 30 degrees per second can be viewed with comfort if all "jerkiness" is removed, but disparity in the image will cause discomfort in some users. Velocities of 60 to 90 degrees per second should be used to move images across the display without expecting the viewer to discern details; jerkiness is not a problem since operators will not be searching the field at this speed.

When the rate of motion is low (up to 10 degrees per second), there is little difference between static and dynamic displays (Farrell and Booth, 1984). Taking a look at the scale below, the "low" motion rate would probably allow high visual acuity without changing illumination or display size. The "medium" motion rate may require some adjustments to be made to either illumination levels or to the display size. Finally, a selection of the "high" motion rate would definitely require adjustments to be made in other contributing factors. These "factors" and adjustments are taken into account in the final image specifications to be computed at the end of this taxonomy.

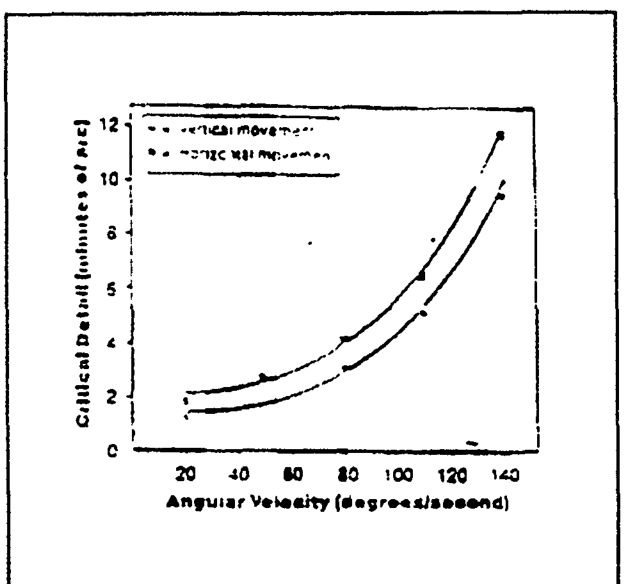
What is the rate of motion across the screen (per second)?

_______ low : 0° - 20°
_______ medium : 20° - 40°
_______ high : 40° - 100°

Movement Rate

Direction of Motion

The direction of motion for the image may be horizontal, vertical, oblique (diagonal), or any combination of the three. According to Booth and Farrell (1979) image velocities of up to about 2.5 degrees per second can be tolerated if the motion is horizontal or vertical, whereas, if the motion is in an oblique direction, a velocity of only <u>one</u> degree per second will reduce visibility. Normally, a display system will be capable of not only horizontal motion or oblique motion only. Therefore, for the purposes of calculating the final image specification in this taxonomy, we will assume the most difficult direction to obtain is necessary, and use the calculation based on oblique direction. As added information for the curious user, the following figure illustrates the effects of visual acuity with target motion in the horizontal and vertical directions:

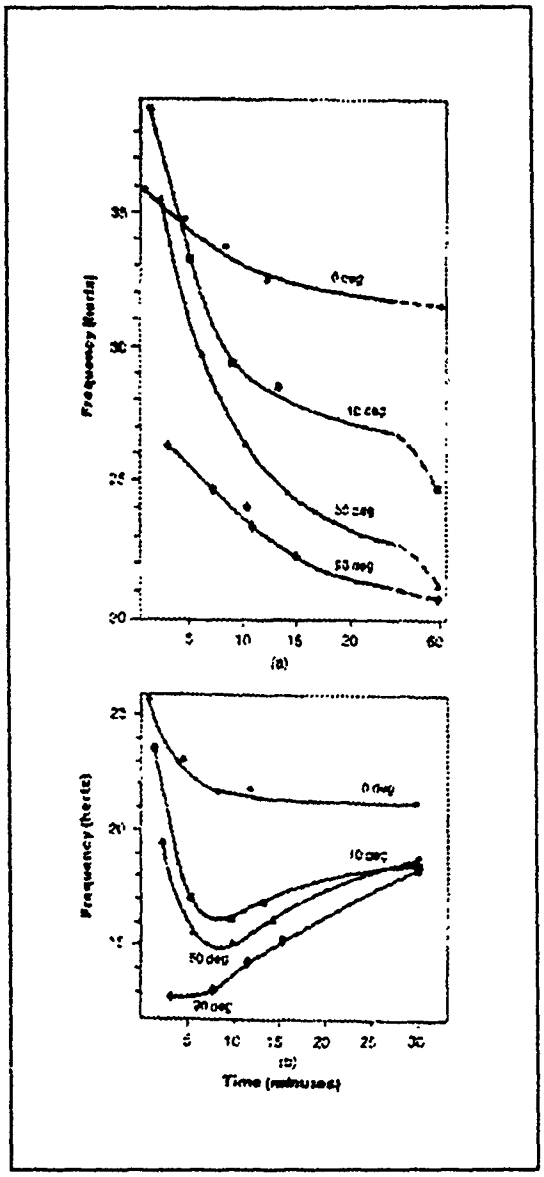


Visual acuity with horizontal and vertical target movement. The ordinate gives the smallest resolvable gap size in a moving Landolt-C target (Miller, 1958).

Retinal Position

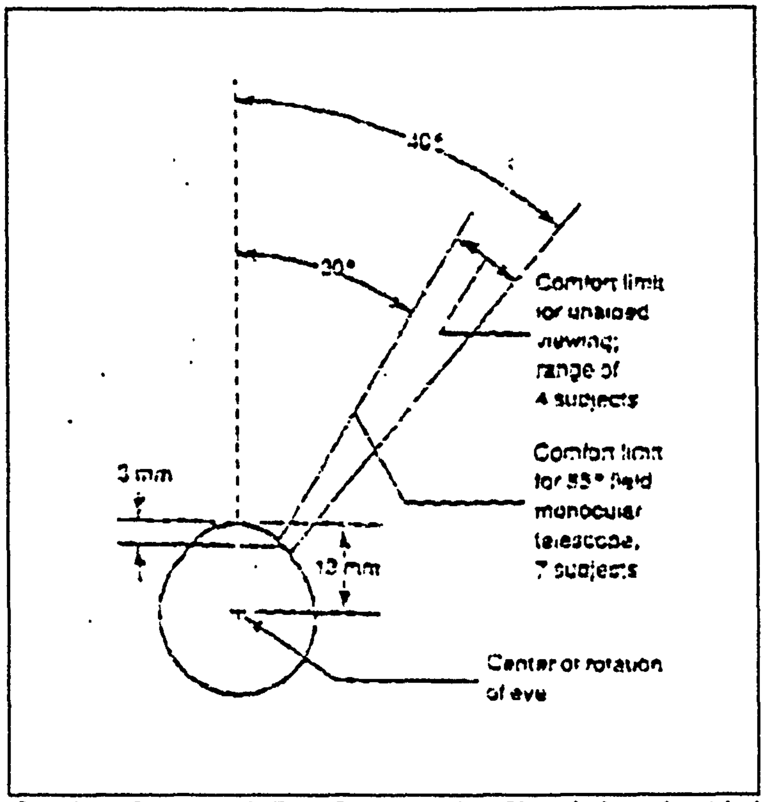
The retinal position is a determinant in the critical flicker frequency. "Critical flicker frequency (CFF) is defined as the lowest frequency at which a light will be perceived as anything but a steady light" (Boff and Lincoln, 1988). The CFF depends on the time-averaged luminance of the flickering target, its location in the visual field, and the observers' state of adaptation (Boff and Lincoln, 1988).

Highest CFF values are found for light adapted observers looking at foveal targets. This relationship is pictured in the following figure.



Critical flicker frequency during dark adaptation. CFF is shown as a function of time in the dark for targets at various angular distances from fixation, as indicated on curves (Lythgoe & Tansley, 1929).

The maximum field of view (FOV) of the normal observer, under the best conditions, is a somewhat irregularly shaped ellipse made up of overlapping monocular fields of the right and left eyes. The FOV extends to approximately 60 degrees of visual angle above and below the center and more than 100 degrees to the left and right (Boff and Lincoln, 1988). (It may be important to note that this visual field declines with adults over 30 to 35 years of age.) The following figure illustrates the comfort limits of eye rotation for unaided and aided viewing. As this figure shows, 30 degrees (and in some instances, up to 40 degrees) should be the maximum visual angles used for comfortable viewing.



Comfort Limits of Eye Rotation for Unaided and Aided Viewing (Farrell & Booth, 1984).

Research indicates that sensitivity to flicker is greater for peripheral targets than for foveal targets (Kelly, 1972 and Kulikowski & Tolhurst, 1973). Maximum sensitivity to light occurs when the angular distance of the target from the fixation point is approximately 20 degrees. Sensitivity to light increases as the distance from fixation increases from 0 degrees to 12-22 degrees. This sensitivity remains fairly constant until 32 degrees, and then it begins to decrease with additional increases in angular target distances from the fovea (Riopelle and Bevan, 1953).

The following question is needed for determination of refresh rate in the final section. The information supplied needs to be stated in degrees, and needs to state how far into the peripheral field of view the displayed image will be located.

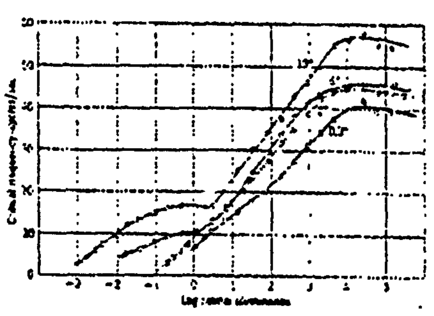
Where does the object fall on the observers' retina?

_________ at fixation position
_________ less than 5° from fovea
_________ between 5° and 30° from fovea
_________ greater than 30° from fovea

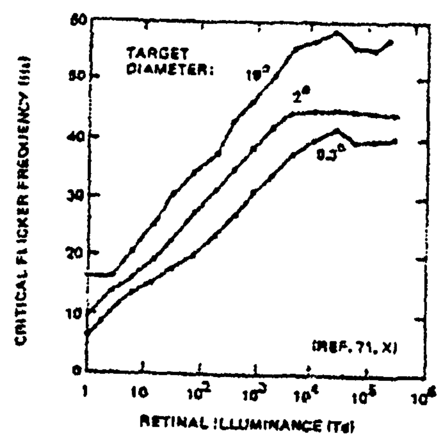
Retinal Position

Flicker Criticality

First of all, there are too many variables that affect critical flicker frequency (CFF) to allow setting a single value that can serve as a design limit in all situations (Farrell and Booth, 1984). There are, however some guidelines that can be followed. According to Boff and Lincoln (1988), the detectibility of a flickering target depends on the luminance of its background. In general, a flickering target will be less visible the higher the background luminance (Boff and Lincoln, 1988). The flicker fusion frequency can be defined as the alternating rate at which fusion of the flickering sources occurs and thus becomes perceptually one source, and the lowest possible flicker fusion frequency is in the 10 Hertz (Hz) range. Under normal lighting, this range will produce a high rate of flicker. The visual system is more sensitive to flicker as brightness increases (Farrell and Booth, 1984). The following figures illustrate the relationship between retinal illuminance and critical flicker frequency.



The dependence of CFF on luminance. The different curves refer to diameter of the test field (Hecht & Shlaer, 1936).



Graph of CFF as a function of target diameter and retinal illumination (Farrell & Booth, 1984).

Thus, as the graphs indicate, the 10 Hz range may be acceptable under certain circumstances (i.e. low retinal illuminance). The typically acceptable flicker fusion frequency, in cycles per second, is in the 30 Hz range, although some flicker will occur at this frequency. For most viewing situations an image depicted at a frequency of 60 Hz does not appear to flicker. As display sizes increase the flicker fusion frequency will need to increase in order to maintain the same level of flicker; i.e., for surfaces larger than 20 degrees with a luminance greater than 340 cd/m^2 (100 fl), 80 Hz is usually adequate (Farrell and Booth, 1984). The following list has been adapted from Farrell and Booth (1984), and gives the general principles governing flicker frequencies:

- CFF increases with luminance
- CFF increases with target area size
- Periphery CFF may be higher or lower than at fixation...Large target sizes show more flicker in the periphery
- CFF increases as temporal modulation increases
- CFF varies with duration of light and dark intervals
- Large variability in flicker sensitivity of individuals
- For test areas greater than one degree, surround luminance has no effect of CFF
- Very brief and high luminance flashes raise the CFF higher than would be predicted by luminance averaged over time.

With all this information in mind, a determination needs to made with regard to the level of flicker that will be allowable in the visual display system being considered at this time.

How critical is the removal of flicker from the display?

_______	Critical	:	Must be eliminated as much as possible
_______	Important	:	Flicker may occur in some instances
_______	Non-critical	:	Flicker is acceptable

Flicker Criticality

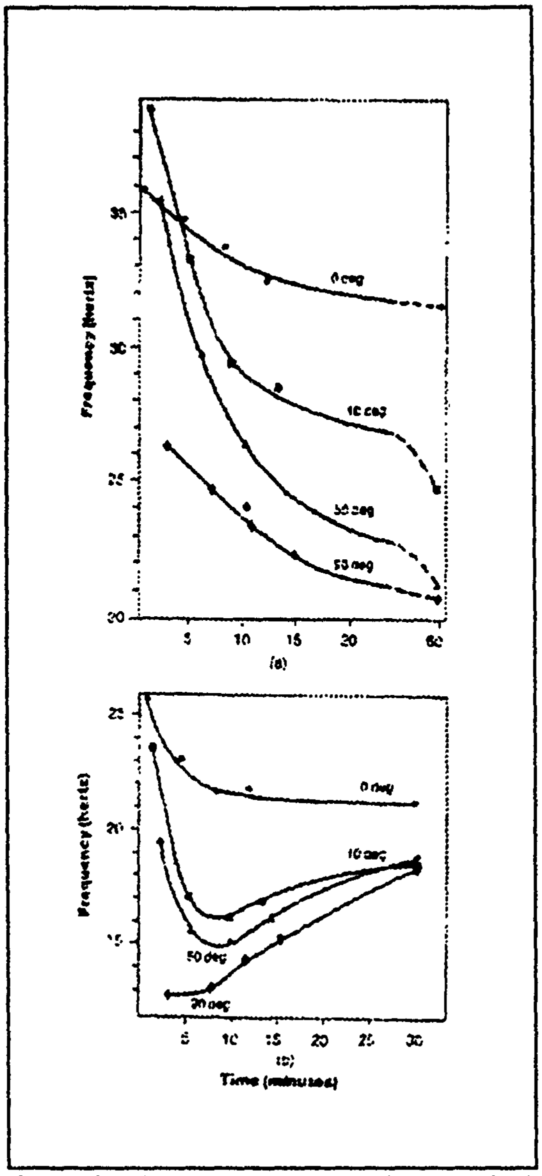
Motion--
NO

STATIC DISPLAY

If you answered "no" to motion, then you have chosen a static display system. The intent of the static display is to present information in a non-moving format. The assumption of choosing a static display is that neither the observer nor the displayed information will be in motion. In order to create a static display, there are a couple of items to consider. First, for a cathode ray tube (CRT) presentation which turns on and off, there will be a need to eliminate flicker in order for the presentation to be considered static. Secondly, there will need to be a minimum amount of presentation time as required by the user. We will also look at retinal position in this section as it will be a determination in the final image specification for refresh rate. Once again, the responses obtained from this section correlate to the final image specifications and relationships to system design.

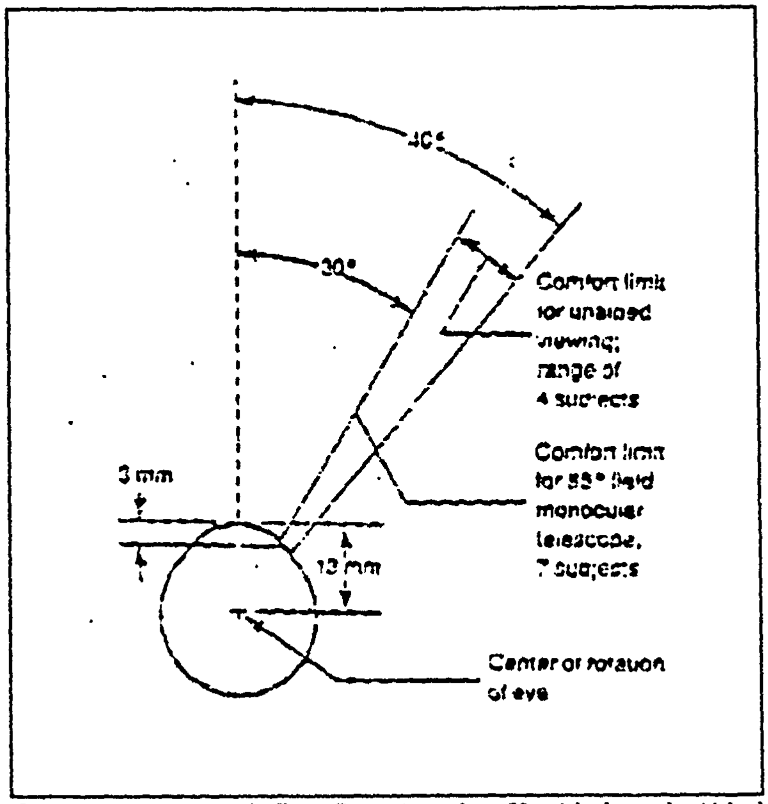
Retinal Position

The retinal position is a determinant in the critical flicker frequency. "Critical flicker frequency (CFF) is defined as the lowest frequency at which a light will be perceived as anything but a steady light" (Boff and Lincoln, 1988). The CFF depends on the time-averaged luminance of the flickering target, its location in the visual field, and the observers' state of adaptation (Boff and Lincoln, 1988). Highest CFF values are found for light adapted observers looking at foveal targets. This relationship is pictured in the following figure.



Critical flicker frequency during dark adaptation. CFF is shown as a function of time in the dark for targets at various angular distances from fixation, as indicated on curves (Lythgoe & Tansley, 1929).

The maximum field of view (FOV) of the normal observer, under the best conditions, is a somewhat irregularly shaped ellipse made up of overlapping monocular fields of the right and left eyes. The FOV extends to approximately 60 degrees of visual angle above and below the center and more than 100 degrees to the left and right (Boff and Lincoln, 1988). (It may be important to note that this visual field declines with adults over 30 to 35 years of age.) The following figure illustrates the comfort limits of eye rotation for unaided and aided viewing. As this figure shows, 30 degrees (and in some instances, up to 40 degrees) should be the maximum visual angles used for comfortable viewing.



Comfort Limits of Eye Rotation for Unaided and Aided Viewing (Farrell & Booth, 1984).

Research indicates that sensitivity to flicker is greater for peripheral targets than for foveal targets (Kelly, 1972 and Kulikowski & Tolhurst, 1973). Maximum sensitivity to light occurs when the angular distance of the target from the fixation point is approximately 20 degrees. Sensitivity to light increases as the distance from fixation increases from 0 degrees to 12-22 degrees. This sensitivity remains fairly constant until 32 degrees, and then it begins to decrease with additional increases in angular target distances from the fovea (Riopelle and Bevan, 1953).

The following question is needed for determination of refresh rate in the final section. The information supplied needs to be stated in degrees, and needs to state how far into the peripheral field of view the displayed image will be located.

Where does the object fall on the observers' retina?

_________ at fixation position
_________ less than 5° from fovea
_________ between 5° and 30° from fovea
_________ greater than 30° from fovea

Retinal Position

Display Duration

The minimum presentation time will be designated by the user. If the presentation time is greater than 100 milliseconds (msec), and if the presentation medium is computer generated, then no consideration for presentation time is needed. If, however, the required presentation time is less than 100 msec, the exact presentation time needed will be required for technical specifications. It is important to note the effect of shorter presentation times: Below 100 msec, the eye will not perceive changes in duration of the target, but will perceive changes in the intensity of the target. Therefore, if you were to continually lessen the target duration time, the target would appear to be "fading away" as the intensity decreased toward the point of nonexistence.

If your presentation time needs to be less than 100 msec, a presentation time should be chosen from the following list. If the presentation time is equal to, or greater than, 100 msec, this box should be skipped.

Please choose the minimum display duration from below:

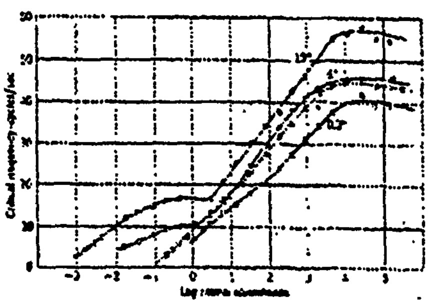
_______ 80 msec _______ 50 msec _______ 33 msec

_______ 25 msec _______ 20 msec _______ 15 msec

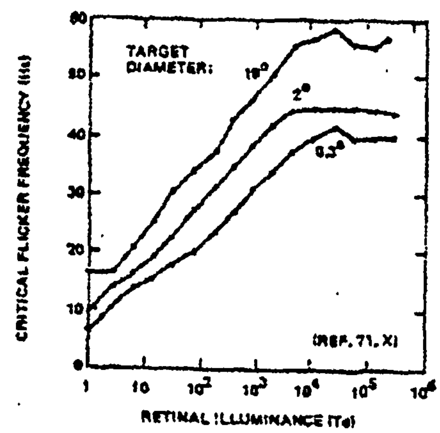
Minimum Display Duration

Flicker Criticality

First of all, there are too many variables that affect critical flicker frequency (CFF) to allow setting a single value that can serve as a design limit in all situations (Farrell and Booth, 1984). There are, however some guidelines that can be followed. According to Boff and Lincoln (1988), the detectibility of a flickering target depends on the luminance of its background. In general, a flickering target will be less visible the higher the background luminance (Boff and Lincoln, 1988), p.168). The lowest possible flicker fusion frequency is in the 10 Hertz (Hz) range. Under normal lighting, this range will produce a high rate of flicker. The visual system is more sensitive to flicker as brightness increases (Farrell and Booth, 1984). The following figures illustrate the relationship between retinal illuminance and critical flicker frequency.



The dependence of CFF on luminance. The different curves refer to diameter of the test field (Hecht & Shlaer, 1936).



Graph of CFF as a function of target diameter and retinal illumination (Farrell & Booth, 1984).

Thus, as the graphs indicate, the 10 Hz range may be acceptable under certain circumstances (i.e. low retinal illuminance). Flicker fusion frequency can be defined as the alternating rate at which fusion of the flickering sources occurs and thus becomes perceptually one source, and the typically acceptable flicker fusion frequency, in cycles per second, is in the 30 Hz range, although some flicker will occur at this frequency. For most viewing situations an image depicted at a frequency of 60 Hz does not appear to flicker. As display sizes increase the flicker frequency will need to increase in order to maintain the same level of flicker; i.e., for surfaces larger than 20 degrees with a luminance greater than 340 cd/m^2 (100 fl), 80 Hz is usually adequate (Farrell and Booth, 1984). The following list has been adapted from Farrell and Booth (1984), and gives the general principles governing flicker frequencies:

- CFF increases with luminance
- CFF increases with target area size
- Periphery CFF may be higher or lower than at fixation...Large target sizes show more flicker in the periphery
- CFF increases as temporal modulation increases
- CFF varies with duration of light and dark intervals
- Large variability in flicker sensitivity of individuals
- For test areas greater than one degree, surround luminance has no effect of CFF
- Very brief and high luminance flashes raise the CFF higher than would be predicted by luminance averaged over time.

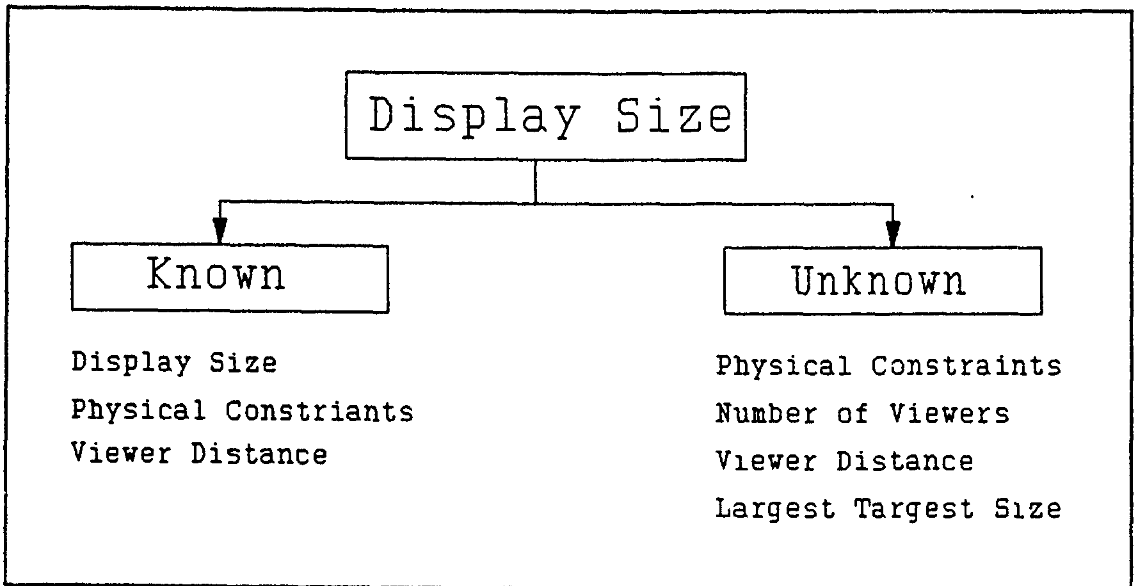
With all this information in mind, a determination needs to made with regard to the level of flicker that will be allowable in the visual display system being considered at this time.

How critical is the removal of flicker from the display?

_______	Critical	:	Must be eliminated as much as possible
_______	Important	:	Flicker may occur in some instances
_______	Non-critical	:	Flicker is acceptable

Flicker Criticality

DISPLAY SIZE CONSIDERATIONS



Display Size Tree

Display Size--
Known

KNOWN DISPLAY SIZE

With the exception of a general consensus that big is good, there is no basis at present for firm design limits on display field size (Farrell and Booth , 1984). Since it is difficult to specify display sizes based on tasks without fully knowing the task's individual requirements (Marsh, 1984), determination of display size is best left up to the instructional designer as he is more intimate with the task at hand. If you said "known" to display size in the diagram, and there are no definite, (small-physical) constraints, then the size of the display may be chosen from a wide assortment of sizes. If there is a known physical constraint please see the section below labeled by that name. The viewer distance will also be determined in this section for use in the image specifications of pixel density.

Display
Size

If the needed display size is known and is at least 13" (measured diagonally), then a choice should be made from the following list. If the needed display is less than 13", skip the following list and use the physical constraints information found in the next section.

Please choose an appropriate visual display size from the list below (all sizes are measured diagonally, in inches):

_______ 13 _______ 17 _______ 19 _______ 21

_______ 25 _______ 36 _______ 120 _______ >120

Display Size

Physical

Constraints

Sometimes the area allotted in the design of a system has been determined by engineering specifications which are completed for an entire environment (such as a real-life simulator). A visual display panel, such as one that may be used in the modeling of a fighter aircraft, may be allotted only a five inch square surface area for visually displaying information. Obviously in a case such as this, a thirteen inch diagonal screen becomes unusable. If there are known physical constraints that require the chosen display size to fit into a small area, please choose from among the physical constraints categories shown below to determine the appropriate display size.

Please choose the category below that best describes the physical space limitation (in inches):

_______ 4 x 3 x 5	_______ 8 x 6 x 9
_______ 19 x 12 x 15	_______ 18 x 16 x 17

Physical Limitations

Viewer Distance

The viewer distance is needed not only for determining display size, but it is also needed for calculating pixel density, which is a final image specification. The choice of viewer distance will be left to the discretion of the user of this document. Viewing distances should be chosen where vision is most effective or most comfortable. Leibowitz and Owens (1978), determined that the eye has a preferred focus distance, referred to as the "resting point of accommodation (RPA)". RPA varies between individuals, but with normal sight it generally lies between one and two meters (40 to 80 inches). This sets the range of image viewing distance that is most comfortable for human vision (Booth and Farrell, 1979).

What is the maximum distance of the viewer(s) to the display?

Please state in feet: ______________________

Viewer Distance

Display Size--
Unknown

UNKNOWN DISPLAY SIZE

If you said "unknown" to display size in the *Display Size Tree* diagram, the display size will need to be determined through calculating the visual angle, through information obtained concerning the largest target size and viewing distance, and in specifying the number of users. The following table shows the optimum, preferred limits and acceptable limits pertaining to display size ratios to viewing distances and a variety of other factors to be considered in a visual display system.

Several tables of display sizes will be presented to you in the final image specifications. These tables incorporate the calculated visual angle, number of observers and viewing distance and allow you to make a display size decision easily.

If there are known physical constraints that require the chosen display size to fit into a small area, please use the physical constraints information found in the next section to determine the appropriate display size.

Physical Constraints

Sometimes the area allotted in the design of a system has been determined by engineering specifications which are completed for an entire environment (such as a real-life simulator). A visual display panel, such as one that may be used in the modeling of a fighter aircraft, may be allotted only a five inch square surface area for visually displaying information. Obviously in a case such as this, a thirteen inch diagonal screen becomes unusable. If there are known physical constraints that require the chosen display size to fit into a small area, please choose from among the physical constraints categories shown below to determine the appropriate display size.

Please choose the category below that best describes the physical space limitation (in inches):

_______ 4 x 3 x 5	_______ 8 x 6 x 9
_______ 19 x 12 x 15	_______ 18 x 16 x 17

Physical Limitations

Number of Viewers

Although the taxonomy makes no suggestions on effective audience sizes for training, the number of viewers does make a difference when selecting a display size. As a general rule, the larger the number of viewers, the larger the necessary screen. The display size must increase as the number of viewers increase to accommodate those viewers seated in the rear and to the sides of the display area. In order to determine the final display size as an image specification, the maximum number of viewers for the display should be used.

Viewer Distance

Maximum viewer distance is needed not only for determining an appopriate display size, but it is also needed for calculating pixel density, which is a final image specification. The choice of viewer distance will be left to the discretion of the user of this document. Viewing distances should be chosen where vision is most effective or most comfortable. Leibowitz and Owens (1978), determined that the eye has a preferred focus distance, referred to as the "resting point of accommodation
(RPA)". RPA varies between individuals, but with normal sight it generally lies between one and two

What is the expected number of simultaneous users of the display?

_______ 1 _______ 2 - 3 _______ 4 - 8 _______ 9 - 15 _______ >15

Number of Viewers

meters (40 to 80 inches). This sets the range of image viewing distance that is most comfortable for human vision (Booth and Farrell, 1979).

What is the maximum distance of the viewer(s) to the display?

Please state in feet: ____________________

Viewer Distance

Largest Target

The largest target size will be used in the final determination of display size. The largest target size needed is the actual target size as it appears on the screen. Do not be concerned, at this point, with the visual arc subtended by the target.

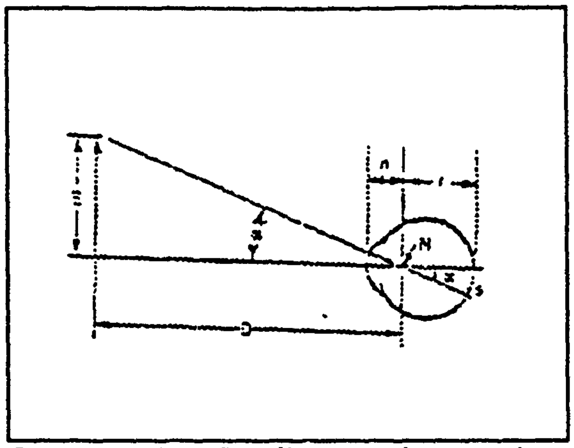
What is the largest target you wish to have fully displayed?

Please state in inches: ____________________

Largest Target Size

Visual Angle

The first step in the final determination of display size is the determination of the visual angle that will be subtended by the eye to the displayed image. A simple formula will be given below for calculating visual angle. The visual angle, along with the number of viewers and the viewing distance will be combined to determine display size in the final image specification for display size. The following figure provides the parameters involved in the calculation of visual angle:



S= target size; D= distance of target from nodal point of eye; N= nodal point; n= distance of nodal point from corneal surface; r= distance of nodal point from retinal surface; s= retinal extent; a= visual angle (Boff and Lincoln, 1988).

The visual angle needed is the visual angle of the target image, and not the entire display. The formula for visual angle is as follows:

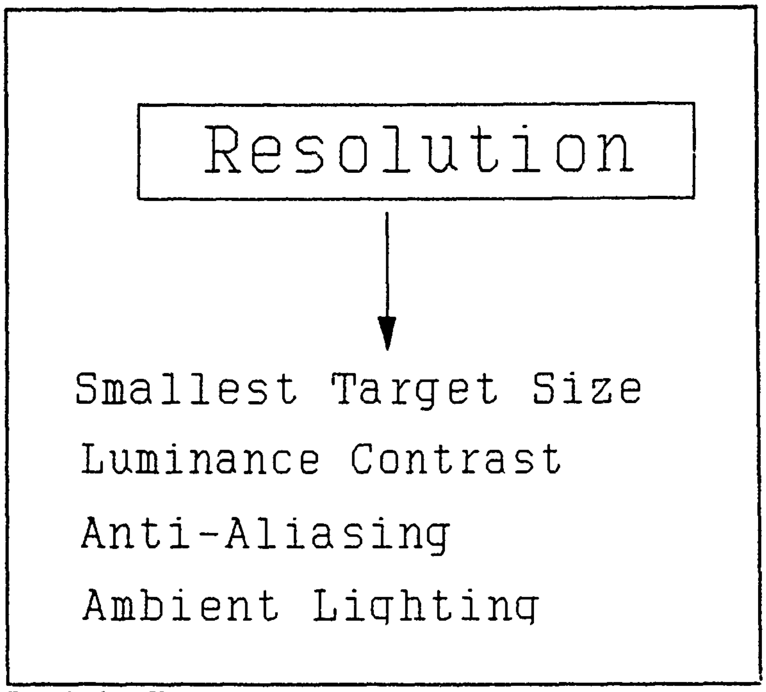
$$VA = \frac{(57.3)(12)(T)}{D}$$

where:
VA = visual angle (in degrees)
T = largest target size (in inches)
D = viewing distance (in feet)

Please record the visual angle determined in the formula: ________________

Visual Angle

RESOLUTION



Resolution Tree

Resolution is a measure of the ability to delineate picture detail. A low resolution display is adequate for relatively large target patterns--shore lines, valleys, and industrial complexes; but where the image is small and must be recognized by form contour, high resolution is required (VanCott and Kincade, 1972). Resolution in cathode ray tubes is usually expressed as the number of scan lines in the vertical dimension of the raster (i.e. the direction perpendicular to the scan lines). When speaking of CRT resolution, Booth and Farrell (1979) note that this type of displayed material is dependent upon the number of active scan lines in the display, the time allotted to write each line and the bandwith of the system. A line of TV resolution is either the light or dark portion of a periodic target, as opposed to the designation of resolution as the number of line pairs (both the light and dark portions of a periodic target) used in optics. Two lines of TV resolution, then, are required to equal one line pair of optical resolution. Resolution of a visual display system will be calculated through information given concerning the smallest target size, contrast luminance, an aliasing determination, and the ambient lighting condition.

Smallest Target Size

The smallest target size will be used in the final determination of pixel density. The smallest target size needed is the actual target size as it appears on the screen.

Luminance

Contrast

What is the smallest target you wish to have fully displayed?

Please state in inches: ____________________

Smallest Target Size

To be visible, information displayed must have either higher or lower luminance than the surrounding areas (Salvendy, 1987). This difference in luminance levels is the luminance contrast. According to Grether and Baker (1972) the luminance contrast is frequently called brightness contrast or simply contrast, and refers to this difference in luminance of the features of the target from its background luminance. This difference is usually stated as a ratio termed the contrast ratio. The minimum contrast ratio acceptable for general display conditions is within the range of 10:1 to 18:1 with a 10:1 ratio being a generally accepted industrial standard for display design (Salvendy, 1987). It is important to note that there is a difference between static and dynamic perceptions of contrast threshold. According to Boff and Lincoln (1988), contrast threshold for moving targets varies little as target distance from fixation increases; however, the contrast required to detect a stationary target increases the further the target is from fixation. As a general rule, as background luminance increases, the minimum contrast needed to detect a target's presence or to judge its detail decreases. Another important note is that a target can be <u>detected</u> at a lower threshold than is required to discern its detail. Therefore, if the task only requires detection of a target, the required contrast threshold will be lower than if the task involves recognition of the target's detail. The level of display luminance is dependent on the type of task to be completed, therefore display luminance will be translated from the choice made between various taskings.

Please choose the description below that best describes the type of task determined for this display system:

_______ Casual examination to locate general features
_______ Performing normal interpretation functions
_______ Extensive, detailed examination of the imagery

Display Luminance Determination

Anti-Aliasing

Aliasing is an error of systems which manipulate data in discrete units, and occurs when the display device attempts to handle details that exceed the system's basic resolving power. This error is most pronounced in pixel-based systems, and it creates a jagged effect (or staircase effect) on edges that are almost vertical or horizontal. Aliasing normally does not occur in high resolution systems and no precautions against it are needed in systems which are in excess of 1500 lines. Aliasing in low resolution systems can be reduced by anti-aliasing procedures.

Anti-aliasing is a technique for disguising the aliasing errors introduced by discrete systems. Aliasing errors found in pixel-based frame stores manifest themselves as jagged edges, but these can be "softened" or anti-aliased, by filtering the shading intensities around the offending pixels to create a smoother transition of color changes. An anti-aliased image will appear slightly blurred or softer to the eye.

Anti-aliasing is a direct system requirement. The choice is left to the user to decide if anti-aliasing features will need to be integrated into the display system chosen.

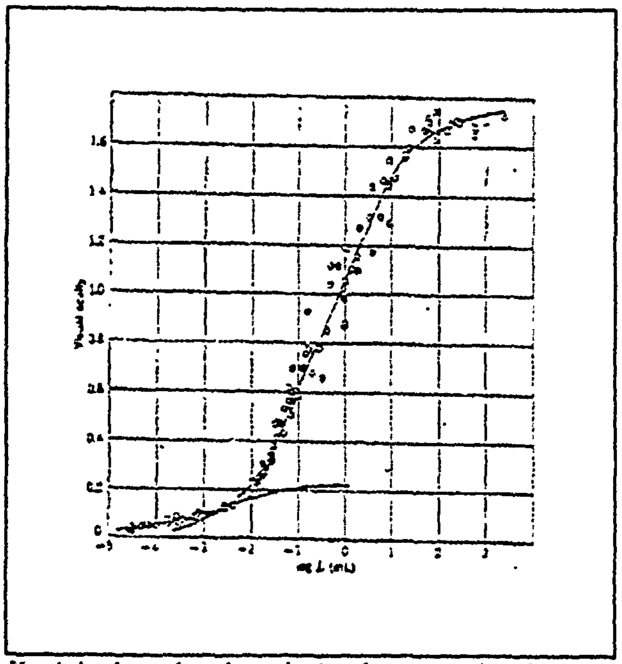
Does the display device require anti-aliasing features?

_______ Yes   _______ No

Anti-Aliasing Determination

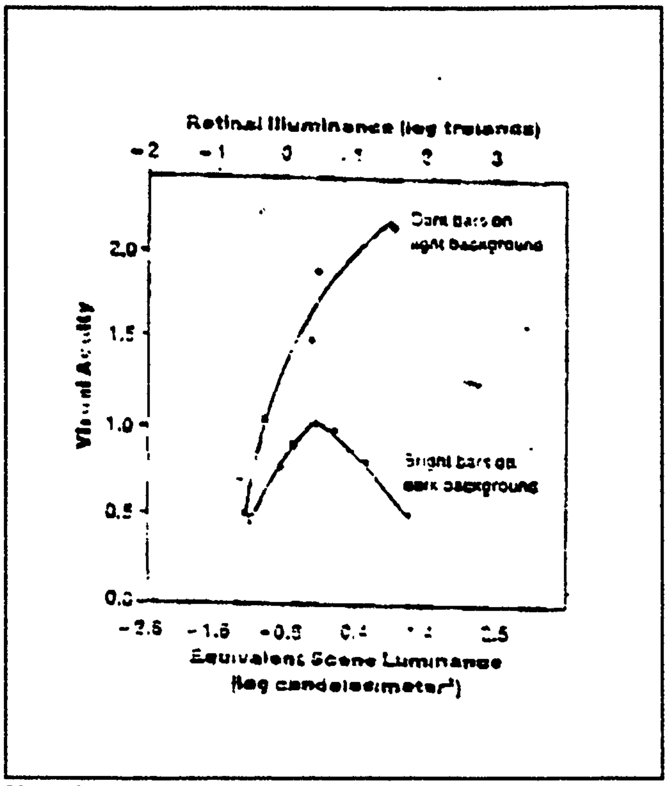
Ambient Illumination

Ambient illumination includes all sources of illumination except those used to display imagery or signals (Farrell and Booth, 1984). Ambient illumination is important with regard to the perception of flicker, to luminance contrast, to color choices as well as choices made pertaining to a monochrome system. A relationship exists between the level of illumination and visual acuity. The following figure depicts the relationship between visual acuity and illumination.



Konig's data for the relation between visual acuity and illumination, as replotted by Hecht (1934). The shallow curve for lower limb of the data is an equation for rods, whereas the upper curve is for cones.

This relationship will determine if a given illumination level is acceptable to produce visually legible images. The choice of which background illumination level to use affects acuity of the observer and the level of illumination necessary to produce legible images. The following figure represents visual acuity as a function of intensity for parallel bar targets.



Visual acuity as a function of intensity for parallel bar targets. Acuity is equal to 1 divided by resolution threshold in min of arc visual angle; normal acuity is = 1.0 (i.e., threshold of 1 min arc) (Bartley, 1941 and Wilcox, 1932).

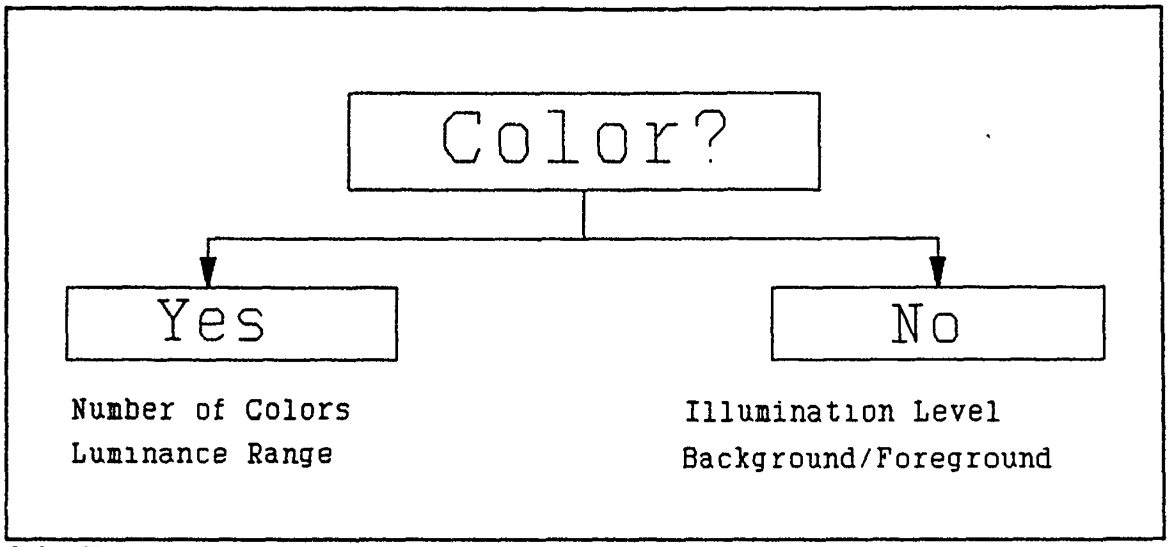
The ambient lighting response will be used in the final calculation of pixel density and will be based on a choice from four common illumination levels.

What will be the predominant ambient lighting condition for viewing the display?

___ Theater lighting: 0.07 to 0.34 cd/m^2
___ Low level office: 30 cd/m^2
___ Routine office : 300 cd/m^2
___ Daylight : 1,000 cd/m^2

Ambient Illumination

COLOR



Color Tree

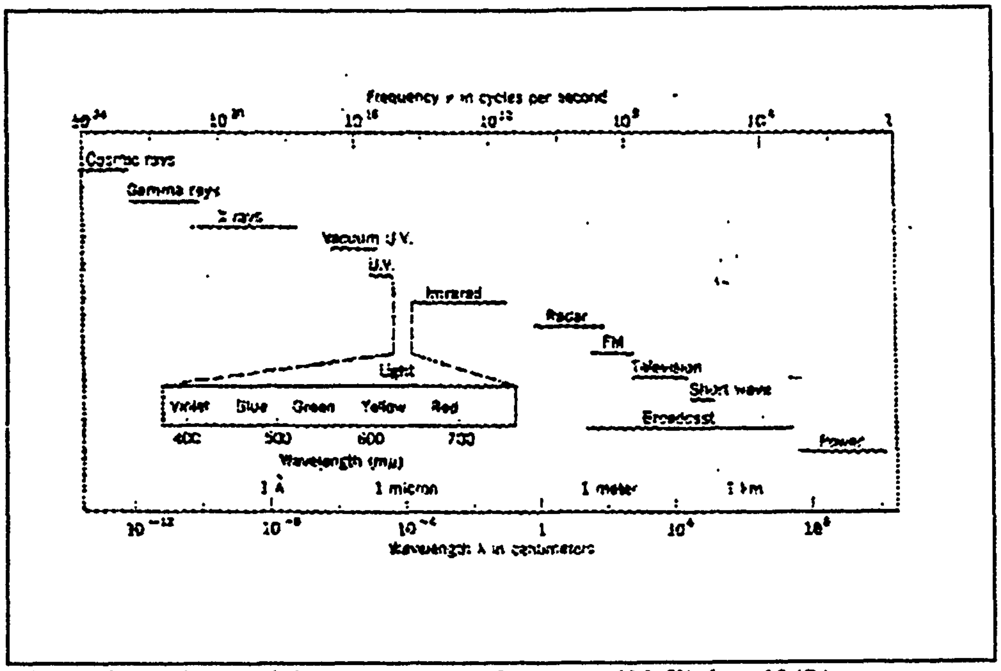
Color--
Yes

COLOR

If you answered "yes" to color, a color system is required, and you will need to choose the number of colors as well as the luminance range to be used in the final image specifications. Normally, color is not a real requirement. Color can be viewed as a nicety except where ease of identification is required. Thus, setting proper limits on the spectrum of colors to be used in a color imagery display will depend heavily on the contribution color is expected to make to the interpretation process (Farrell and Booth, 1984). To determine final specifications, the number of colors needed as well as the luminance range will need to be obtained. The luminance range will be based on information given in the resolution determination of luminance contrast, and will not be repeated here.

Number of
Colors

Limits exist to the number of reasonable codeable colors available. The preferred limit of different colors (hues) is nine (Sanders and McCormick, 1987). These hues fall within the visible spectrum of human vision as shown in the figure below:



The Radiant Energy (electromagnetic) Spectrum (McKinley, 1947).

The following list of the number of colors available is a guideline based on current computerized images. This is not an exact list, but the chosen number will be considered as a final specification.

Please choose the number of colors for this system:

_______ 4 _______ 8 _______ 16 _______ 32

_______ 64 _______ 128 _______ >128

Number of Colors

Adaptation of observer. One important note is that it is assumed the observers will be adapted to the surrounding light. As added information, one should realize that a dark adapted observer takes less time to adapt to a light source than a light adapted observer trying to adapt to darkness.

Color--
No

MONOCHROME

If you answered "no" to color, a monochrome system has been chosen. A monochrome display consists of a foreground color and a background color only. Normally, the difference between the foreground and background is basically described as dark and light (i.e. a light color foreground on a dark color background or vice-versa). Because of the limitation of a monochrome system, the ambient illumination along with the luminance contrast become important considerations. The choice of either a light foreground on a dark background or a dark foreground on a light background will also affect observer variables and therefore should be considered.

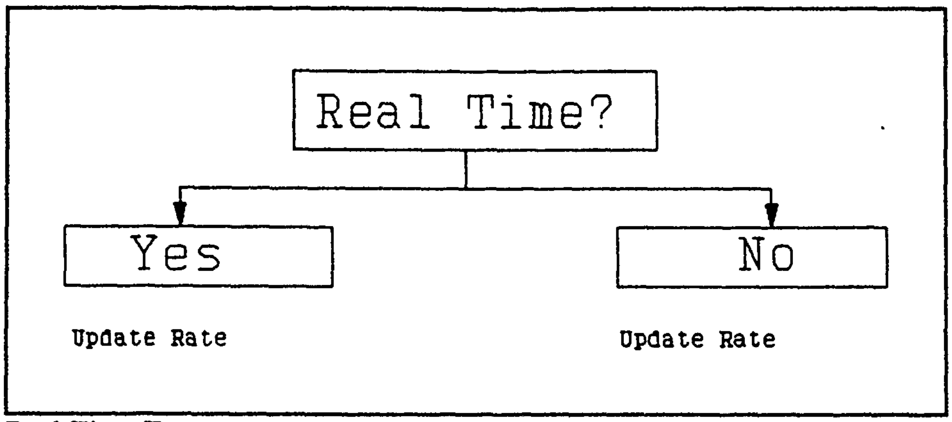
Ambient
Illumination

Ambient illumination was discussed in the previous section, *Resolution*. The ambient illumination was determined by one question concerning the expected lighting condition where the display system will be housed. If the response needs to be modified, please return to that section to make the modification. The information will not be repeated here as no new information pertaining to a monochrome system should affect the response given previously.

Background/
Foreground

The decision as to which orientation is best for this display system is left up to the user. This category will not be used in the final image specification as most computerized images allow the user to change the orientation of the foreground and background. Other systems will normally show the background and foreground in an expected manner; i.e. a monochrome (black and white) filmstrip will show a positive picture (those things in the environment that are light will remain so, and those things in the environment that are dark will normally be displayed as such) versus a negative image (like a negative of a photograph). It may be important to note the "a sufficiently large dark object causes a discriminable drop in the retinal illuminance in the region of the image. A very small object, on the other hand causes so small a reduction in luminance that its presence is not detected" (Grahm, 1965). Therefore, if a light background and dark foreground is chosen, care should be taken in determining the target size such that it is not so large as to cause a substantial decrease in the luminance range of the display.

REAL TIME



Real Time Tree

For dynamic displays
Real Time--Yes

The use of the term "real time" in the generation of images is an artificial convenience. Imaging systems present information in a discontinuous fashion. Complete images are sent to the screen and then persist for short periods of time. Systems termed "real time" operate at speeds great enough such that the human visual system does not perceive the discontinuous signals sent by the imaging system (Vince, 1984 and Rogers & Earnshaw, 1987). Individual frames or pictures are strung together and then presented at speeds fast enough such that the images appear to move smoothly. The number of times that an image is sent to the screen for portrayal is termed "update rate" (Rogers and Earnshaw, 1987). The greater number of updates in the presentation, the more continuous the image appears to the human visual system.

The updating of scenes is a characteristic of all image generation systems. Photographs can be considered to have an update rate of one frame. Obviously one photograph is insufficient to portray image movement. But, by placing many individual photographs together and imaging them sequentially, movement can be portrayed. Movies work in this fashion (Vince, 1984). The portrayal of continuous movement is the basis for the term "real time." Images that move in real time, generated in real time, move smoothly across the screen. Real time systems are also considered to be interactive (Freeman, 1980). The motion rates and directions should be capable of being changed through dynamic user interactions. If the system can adjust and make these changes such that the image appears to change instantaneously with user commands, then this system is termed "real time." For example, if in an interactive driving simulator, a subject turns his steering wheel to make a left hand turn, and the system continues to represent his movement in a forward direction, even for 500 milliseconds, then the system can not be denoted as "real time." The system is not capable of updating the displayed image with new information quickly enough to respond to the subjects inputs.

For images to transition smoothly across the screen and to have users responses seemingly portrayed instantaneously, the system must have update rates of equal to or greater than thirty frames per second (fps). Systems that operate at slower update rates will appear discontinuous at times (Vince, 1984 and Castleman, 1979).

The update rate of a system is intimately tied with the system processing speed and the complexity of the scene (Freeman, 1980). A scene is either generated through algorithms which determine image portrayal surfaces or the images are accessed from some storage medium. With either method, the correct sequences of images and the correct viewing angle of the image must be portrayed. Complex images require more data to be organized prior to presentation. The speed at which a system accesses or generates these images is critical to the update rate. Systems that cannot generate the required thirty fps while portraying view point changes, can not update the information quickly enough for instantaneous user interaction or continuous motion to be perceived.

When asked if the system requires real time portrayal of user interactions an answer of yes, immediately indicates that the generation system must be capable of presenting the image at rates greater than thirty fps. Portrayal of user interaction in "real time" requires that the processing speeds of the system must be fast enough to depict image changes as they occur.

For static images
Real Time--No

When a static image is desired, real time processing is not required, and an update rate of 10 fps is considered sufficient for any user interactions.

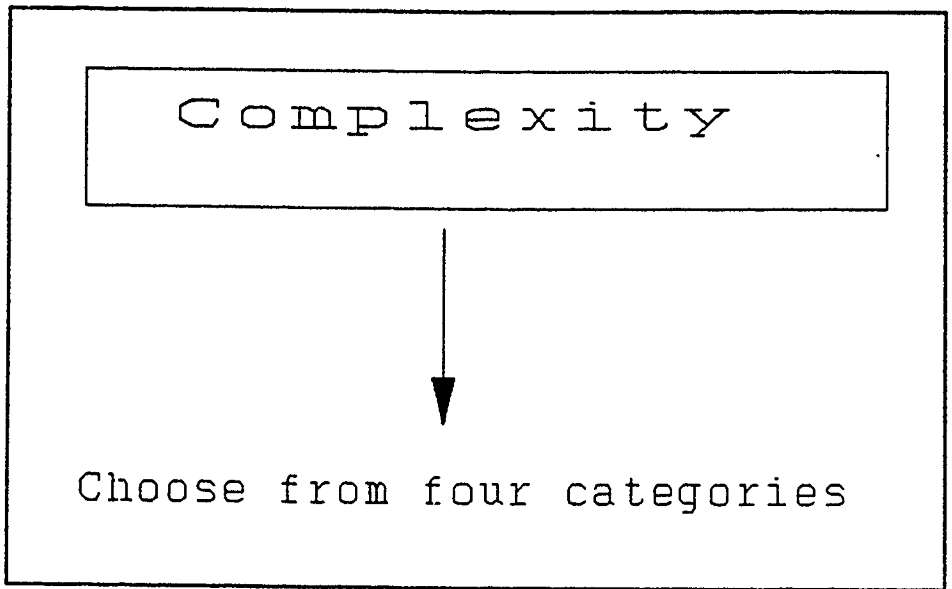
The final image specification for this section will come directly from the question below. A yes or no answer will directly correlate with an update rate as an image specification.

Does the system require the images to be displayed in a real time manner ?.

________ Yes
________ No

Update Rate Determination

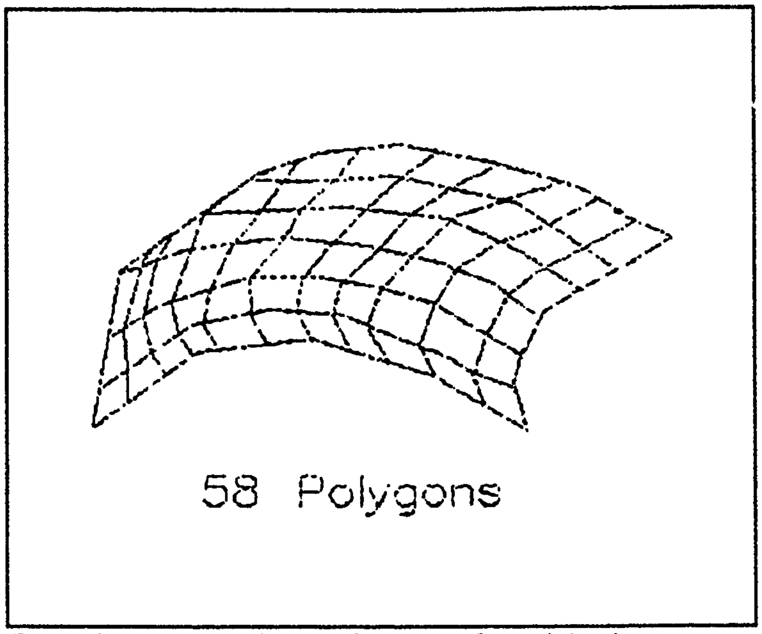
SCENE COMPLEXITY



Complexity Tree

Most image generation systems use polygons to model the visible surfaces of objects. The number of polygons increase in proportion to the number of graphical objects and textures present in the displayed scene. To provide a very high quality picture, we must be able to display large numbers of polygons. For example, if we are modeling a room, we might want to include portraits on the wall or Persian rugs on the floor. These objects could be modeled by a million polygons to recreate the detail or by few polygons to produce a very low quality picture such as carton graphics.

The use of polygons such as squares, rectangles, or triangles is simple when the image is uncomplicated. Many geometric shapes are polygons themselves and are easy to reproduce. Curved surfaces represent some additional difficulties. The flat surfaced polygons typically used in generated scenes approximate a curve by creating a series of straight line segments as edges (as shown in the figure below). Complicated surfaces, curved, require more polygons to image the object.



Example of How Polygons Construct Curved Surfaces.

A problem exists in the determination of number of polygons in the scene because the information contained in texture patterns cannot be easily counted. How texture is counted as a number of polygons is often fraught with individual differences. Scenes that appear simple to non-experts may actually require more than a million polygons and processing times of hours or days. On the other hand, flight scenes that appear complex may in fact be quite simple to produce, i.e., they require few polygons for modeling. To illustrate this point look at the performance summary table below for the a description of how many polygons are required to portray the shown scenes. (Computer Graphics 1981).

Performance summary						
				percent time by routine		
picture	polys	edges	cpu time* (seconds)	scan convert	shade	misc
Figure 6	23554	70661	341	36	61	3
Figure 7	32000	44000	520	60	40	-
Figure 9	12492	19450	320	20	80	-
Figure 10	18188	28421	250	70	30	-
Figure 11	1800	2760	16	41	58	1

*all times are for 512x512 images without anti-aliasing

Processing Statistics are given for five of the pictures found in figure 17 (Computer Graphics, 1981).

At the high end of the capabilities of polygon processing in current technology is at approximately 3000 per channel for a real time system with three channels available. Approximately one million polygons per channel are available with non-real time systems. Of course, the maximum number of polygons processed by a system will increase in proportion to new technology development.

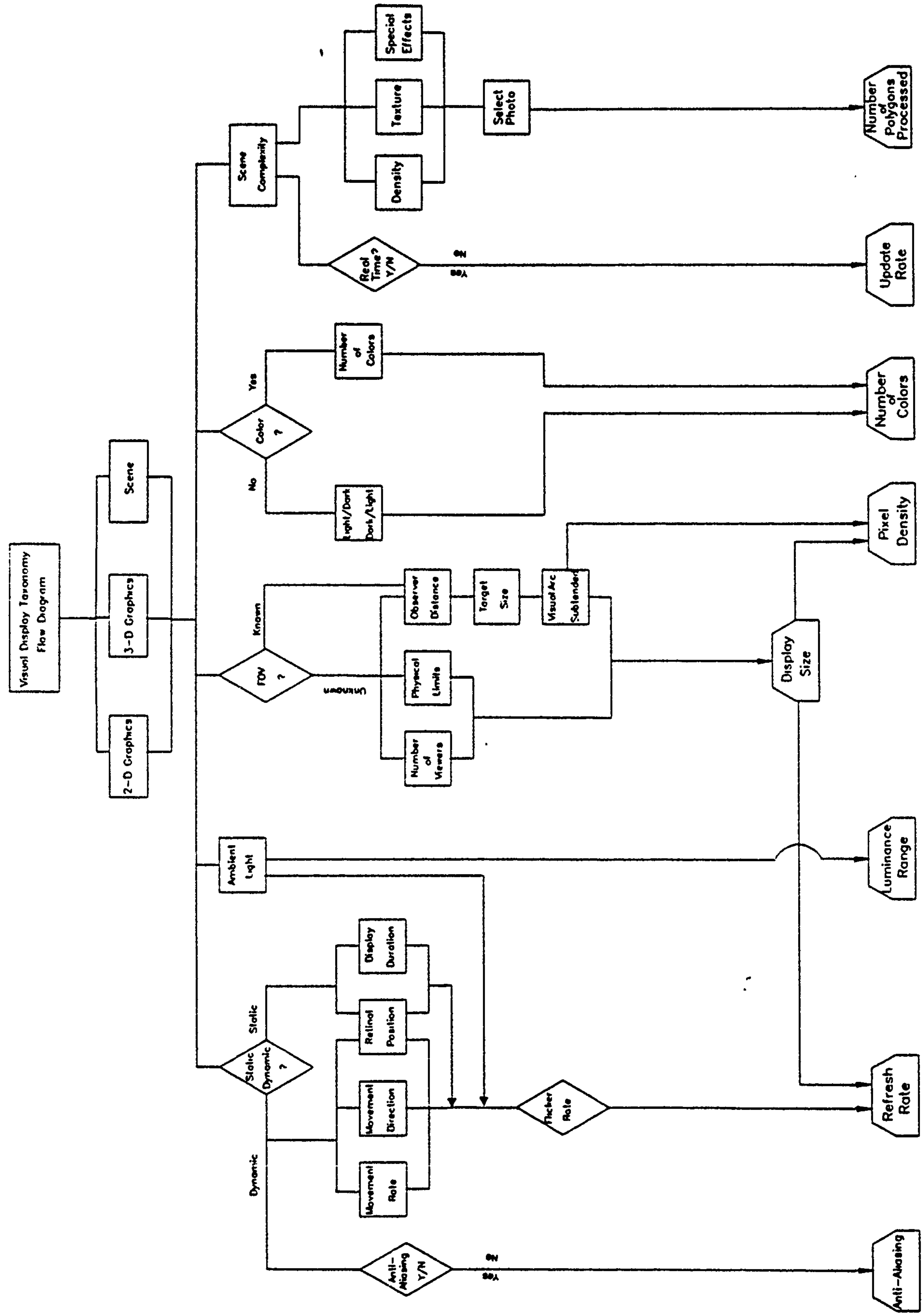
We have chosen to use the number of polygons required to generate a scene as our measure of scene complexity. While hardware may change over time, it is unlikely that the number of polygons within an image or scene will change. The identical scene produced by either high end or conventional hardware makes little difference if the number of polygons present are the same. There needs to be a more uniform method established in counting polygons within a scene; perhaps this will be achieved through standardization. In the final image specifications, you will be asked to select one set of four groupings of photographs that represent different levels of scene complexity (number of polygons). The set chosen must be the one that most closely resembles the level of scene detail and scene complexity required by the specific application. No question will be asked for scene complexity in this section of the taxonomy as the photographs will be seen in the final image specification section.

Final Image Descriptions for a Graphical Presentation

The following section leads through the necessary computations to produce the final image descriptions needed for a graphical display. This section will contain eight subsections as final image descriptions: anti-aliasing determination, refresh rate, display size, luminance range and contrast, pixel density, number of colors, update rate, and the number of polygons processed. At this point in time, these eight descriptions will provide enough information for the user of this taxonomy to communicate with engineers and other designers of visual display systems.

The decision flow diagram for graphics (found on the following page) should prove to be a helpful visual aid as you work through this section. The eight final image descriptions can be found at the bottom of the flow diagram. These description names will be the titles of each of the subsections to follow in the text. If you begin with one of the image description boxes and follow the flow "backward" you should be able to discern the path chosen for the subsection you're working through. Some subsections may not contain all the boxes in the flow; these boxes will not have a corresponding shaded box in the *Initial Considerations*, and therefore should pose no problem in calculations.

Before beginning with this section, all questions (in shaded boxes) from the *Initial Considerations--Graphics* section should be complete with responses. These responses should be in front of you as you work through this section.


Visual Display Taxonomy Flow Diagram
2-D Graphics
3-D Graphics
Scene
Static Dynamic ?
Static
Dynamic
Display Duration
Retinal Position
Movement Direction
Movement Rate
Flicker Rate
Anti-Aliasing Y/N
Yes
No
Anti-Aliasing
Refresh Rate
Ambient Light
Luminance Range
FOV ?
Known
Unknown
Observer Distance
Target Size
Visual Arc Subtended
Physical Limits
Number of Viewers
Display Size
Pixel Density
Color ?
Yes
No
Number of Colors
Light/Dark Dark/Light
Number of Colors
Scene Complexity
Real Time? Y/N
Yes
No
Update Rate
Density
Texture
Special Effects
Select Photo
Number of Polygons Processed

ANTI-ALIASING

Information concerning aliasing and anti-aliasing techniques was given in the *Graphics* section. A yes-or-no (to these techniques) question was given, and the answer should be in front of you now. The answer to this question correlates directly with the image description, and therefore, no other calculation is needed. The question will be repeated here for your convenience:

Does the display device require anti-aliasing features?

_______ Yes _______ No

Anti-Aliasing Determination

REFRESH RATE

Refresh rate is determined using information obtained concerning the retinal position, minimum display duration, ambient light condition, and the flicker criticality chosen. The determination of refresh rate is critical to the system in that higher refresh rates appear to flicker (turn on and off) less than those systems with lower refresh rates (this assumes the display system uses a CRT or like display which turns on and off regularly). Thus, the main focus for determination of refresh rates is in the elimination of flicker from the display environment. Critical flicker frequency (CFF) is defined as the lowest frequency at which a light will be perceived as anything but a steady light. It is difficult to determine the CFF for all conditions that the display will be viewed under. General guidelines are available, however, and will be applied in the final description. "The display should be 'flicker free' for at least 90 percent of a sample of the user population under conditions representative of actual use" (ANSI/HFS).

The following boxes contain information derived from the shaded boxes from *Graphics* along with refresh rates (in bold) measured in hertz (hz) levels:

The object will fall on the observers' retina:

--at fixation position	= **20 Hz**
--less than 5° from fovea	= **30 Hz**
--between 5° and 30° from fovea	= **45 Hz**
--greater than 30° from fovea	= **60 Hz**

Retinal Position

The chosen minimum display duration is:

--100 msec or more	= **10 Hz**	--25 msec	= **40 Hz**
--80 msec	= **15 Hz**	--20 msec	= **50 Hz**
--50 msec	= **20 Hz**	--15 msec	= **60 Hz**
--33 msec	= **30 Hz**		

Minimum Display Duration

The rate of motion across the screen (per second) will be

--low	=15 Hz
--medium	=30 Hz
--high	=60 Hz

Movement Rate

The predominant ambient illumination for viewing the display is:

--Theater lighting	= 10 Hz
--Low level office lighting	= 30 Hz
--Routine office lighting	= 50 Hz
--Daylight	= 80 Hz

Ambient Illumination

A refresh rate should now be selected for each of the above variables. Chances are the hertz levels are not all the same, but a single value is needed for refresh rate. The highest level, lowest level, or an average of levels will be used depending upon the flicker criticality determination.

Removal of flicker from the display is:

--Critical	: Choose the largest hertz value for refresh rate
--Important	: Add all hertz levels. If minimum display duration is less than 100 msec then divide by four. If minimum display duration is 100 msec or greater, subtract 10, and divide by three.
--Non-critical	: Choose the smallest hertz value for refresh rate

Flicker Criticality

Flicker criticality was the final determinant for refresh rate, and therefore is an important consideration. Other variables can affect refresh rates by affecting critical flicker frequency. For instance, the type of phosphors used in a CRT display can require different refresh rates to maintain similar CFF thresholds. "The relative amount of flicker is related to the persistence characteristics of the phosphor" (Boff, 1988). Display luminance can also affect flicker, thereby affecting refresh rates: "Flicker in CRTs cannot be noticed at a 60 hz refresh rate unless display luminance exceeds 620 cd/m^2" (Boff, 1988). The observer should also be considered fully adapted to the lighting environment. Transient adaptation of the viewer may allow flicker to be perceived, whereas at final adaptation levels the image will not appear to flicker.

DISPLAY SIZE

Display size can be determined in one of three ways: first, the user can have a predetermined display size, small, physically limiting dimensions may be present, or the display size can be calculated using the anticipated viewing distance, the size of the largest character, and the expected number of simultaneous users of the display. If the user has a predetermined display size, that size should be used, and the rest of this section can be overlooked. If the visual display system must be housed in an area less than 13 inches (measured diagonally) use the following information to determine the field of view:

The best description of the physical limitation is:

	Field of View
-- 4"x 3"x 5"	= 5"
-- 8"x 6"x 9"	= 9"
--19"x12"x15"	= 15"
--18"x16"x17"	= 19"

Physical Limitations

If the display size is unkown, please have ready the visual angle that was calculated in the *Initial Considerations* section. The remainder of the shaded boxes from the *Initial Considerations* may be ignored; they were used in the determination of the visual angle.

The calculated visual angle for this system is ________________.

Visual Angle

In order to simplify the determination of a display size, tables are provided at the end of this section that may be used to "look-up" an appropriate display size. The tables are based on the responses given for visual angle, the expected number of viewers, and the maximum distance of the viewer(s) from the display. The tables can be used to determine the field of view required by this display system application. It should be noted, however, that these recommendations should not be considered as absolute values. There are no research findings linking human performance to display size requirements. The only findings indicate that larger fields of view can inhibit performance.

Viewing Distance (feet) \ Visual Angle (Degrees)	5	10	20	50	120
1.5	13	17	25	48	126
3	17	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is one. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

Viewing Distance (feet) \ Visual Angle (Degrees)	5	10	20	50	120
1.5	15	17	25	48	126
3	17	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is between two and three. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

Visual Angle (Degrees)

Viewing Distance (feet)	5	10	20	50	120
1.5	17	19	25	48	126
3	19	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: <u>Expected number of users is between four and eight</u>. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

Visual Angle (Degrees)

Viewing Distance (feet)	5	10	20	50	120
1.5	19	21	25	48	126
3	21	25	48	126	
7	25	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: <u>Expected number of users is between nine and fifteen</u>. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

Viewing Distance (feet)	Visual Angle (Degrees): 5	10	20	50	120
1.5	19	25	48	48	126
3	25	48	48	126	
7	48	48	126		
16	48	126			
33	126				

Diagonal Display (Inches)

Display Size Recommendations: Expected number of users is greater then fifteen. Recommendations are based on largest target size in minutes of arc, viewing distance and number of expected users.

PIXEL DENSITY

Pixel density will be determined in much the same manner as found in the determination of an unknown display size, using the same visual angle. Before pixel density can be determined, the presentation size of the image, the viewing distance, adn the display size (from the previous subsection) should be in front of you at this time.

The visual angle of the image is ________.

Smallest Image Size

Please state the viewing distance (in feet) ______________

Viewing Distance

The display size for this system is __________

Display Size

Once the answers to these questions have been chosen, use the following tables to find the appropriate pixel density. Find the graph that represents the size of the target image (converted to minutes of arc); locate the viewing distance, and display size. The required pixel density will be found in the table containing the given information.

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 1	5	10	20	50	120
1.5	640x480	640x480	512x512	640x200	640x200	640x200
3	640x480	512x512	640x200	640x200	640x200	
16	512x512	640x200	640x200	640x200		
33	640x200	640x200	640x200			
66	640x200	640x200				
98	640x200					

Pixel Density Recommendations (2-D, 3-D graphics) for display size *__Diagonals of between 13 and 15 inches__*. *Recommendations are based on smallest critical detail in minutes of arc, viewing distance, and display size diagonal.*

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 1	5	10	20	50	120
1.5	1024x1024	1024x1024	640x640	640x640	640x480	640x480
3	1024x1024	640x640	640x480	640x480	640x480	
16	640x640	640x480	640x480	640x480		
33	640x480	640x480	640x480			
66	640x480	640x480				
98	640x480					

Pixel Density Recommendations (2-D, 3-D graphics) for display size *__Diagonals of 17 inches__*. *Recommendations are based on smallest critical detail in minutes of arc, viewing distance, and display size diagonal.*

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 1	5	10	20	50	120	
1.5	2048x2048	1024x1024	1024x1024	1024x1024	640x640	640x640	640x640
3	1024x1024	1024x1024	1024x1024	640x640	640x640		
16	1024x1024	1024x1024	640x640	640x640			
33	1024x1024	640x640	640x640				
66	640x640	640x640					
98	640x640						

Pixel Density Recommendations (2-D, 3-D graphics) for display size *__Diagonals of 25 inches__. Recommendations are based on smallest critical detail in minutes of arc, viewing distance, and display size diagonal.*

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 1	5	10	20	50	120	
1 5	2048x2048	2048x2048	2048x2048	1024x1024	1024x1024	1024x1024	640x640
3	2048x2048	2048x2048	1024x1024	1024x1024	1024x1024		
16	2048x2048	1024x1024	1024x1024	1024x1024			
33	1024x1024	1024x1024	1024x1024				
66	1024x1024	1024x1024					
98	1024x1024						

Pixel Density Recommendations (2-D, 3-D graphics) for display size *__Diagonals of 48 inches__. Recommendations are based on smallest critical detail in minutes of arc, viewing distance, and display size diagonal.*

Viewing Distance (feet)	Visual Angle (Minutes of Arc) 1	5	10	20	50	120	
1.5	4086x4086	2048x2048	2048x2048	2048x2048	1024x1024	1024x1024	640x640
3	2048x2048	2048x2048	2048x2048	1024x1024	1024x1024		
16	2048x2048	2048x2048	1024x1024	1024x1024			
33	2048x2048	1024x1024	1024x1024				
66	1024x1024	1024x1024					
98	1024x1024						

Pixel Density Recommendations (2-D, 3-D graphics) for display size Diagonals of 126 inches. Recommendations are based on smallest critical detail in minutes of arc, viewing distance, and display size diagonal.

LUMINANCE RANGE AND CONTRAST

The level of display luminance is highly dependent on the type of task being completed. Thus, the determination of display luminance is taken directly from the following information concerning the task to be performed using this display system:

The description below that best describes the type of task determined for this display system is:

--Casual examination to locate general features	**: 35 cd/m^2 (10 fl)**
--Performing normal interpretation functions	**: 85 - 340 cd/m^2 (25 - 100 fl)**
--Extensive, detailed examination of the imagery	**: 1750 cd/m^2 (500 fl)**

(Farrell and Booth, 1984; and ANSI/HFS, 1989)

Luminance Contrast Determination

NUMBER OF COLORS

The number of colors is determined by the user of this document. In the *Initial Considerations* section, a choice was given between a monochrome system and a color system. Choices were also presented, for a color system, as to how many colors were preferred for this display system. The responses to these choices directly correspond to final image descriptions, but will be repeated here for your convenience:

Please choose the number of colors for this system:

_______ 2 (monochrome)

_______ 4 _______ 8 _______ 16 _______ 32

Number of Colors

UPDATE RATE

Update rate is the number of times that the system updates screen information. Update rates in the low range are sufficient for most applications. In the *Initial Considerations* section, update rate was discussed as a function of the need for a real time system. Low update rates in the range of 5 hz are acceptable for most applications, however, if your system will be processing in real time, higher update rates may be needed. This would need to be discussed further with the system designer.

NUMBER OF POLYGONS PROCESSED

In determining the level of polygon processing required, four groups of pictures are asked to select a group of pictures that most closely represents your application. The selection of a group of pictures translates directly into a required level of polygons processed or displayed in re-creating scenes of this type. Thus, the determination of the number of polygons processed (PP) is drawn directly from the choice of which group is chosen from below.

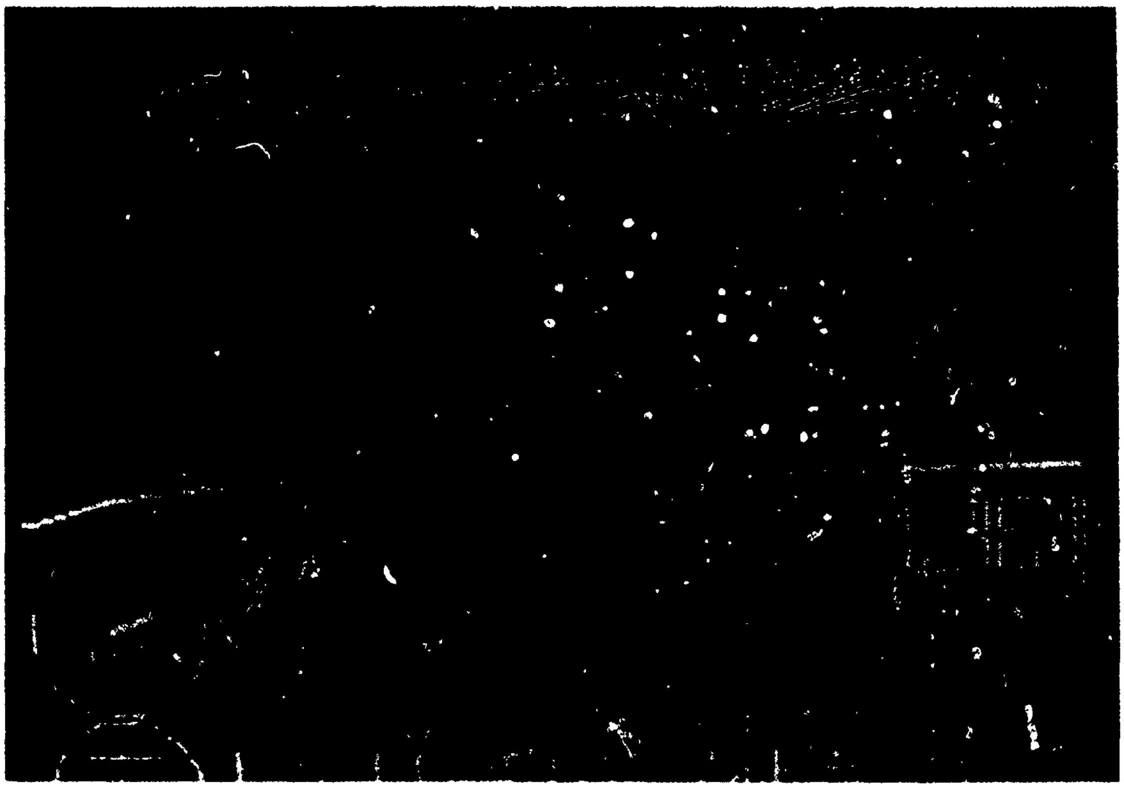


Photo 1. Group 1: Example of a generic flight scene which requires 70 polygons to model the scene.

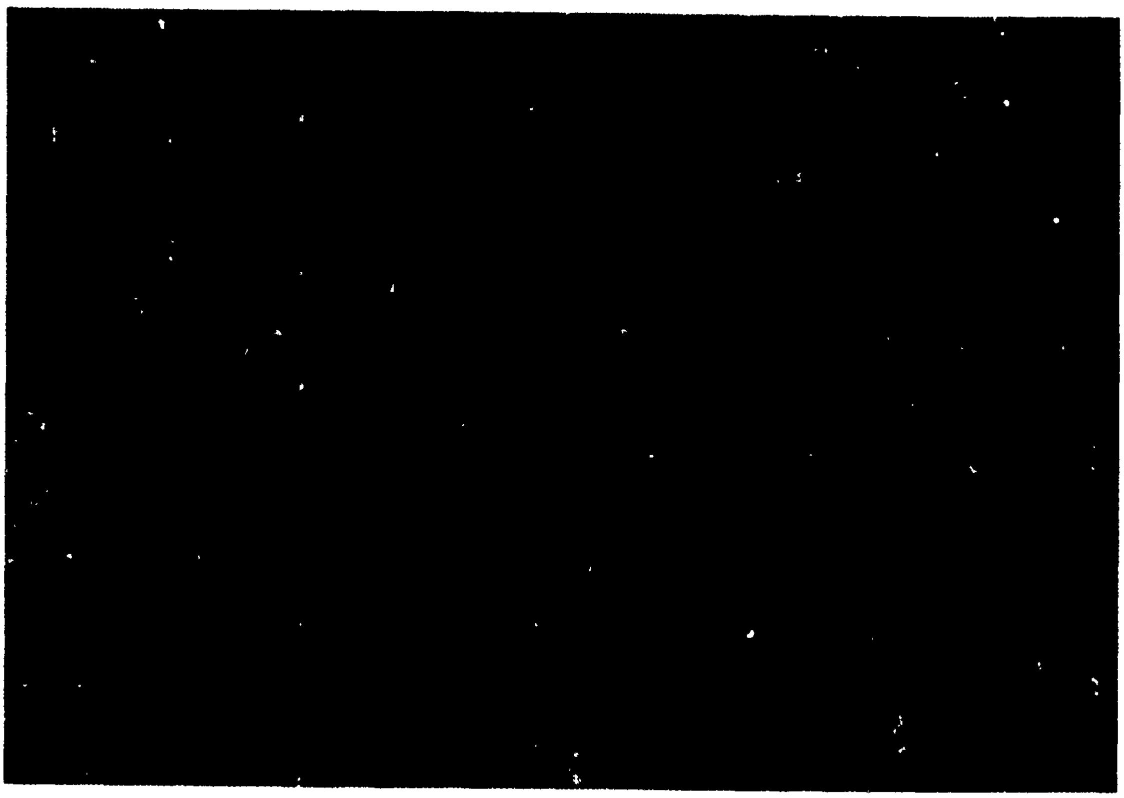


Photo 2. Group 1: Example of a low level generic flight scene which requires 150 polygons to model the scene.

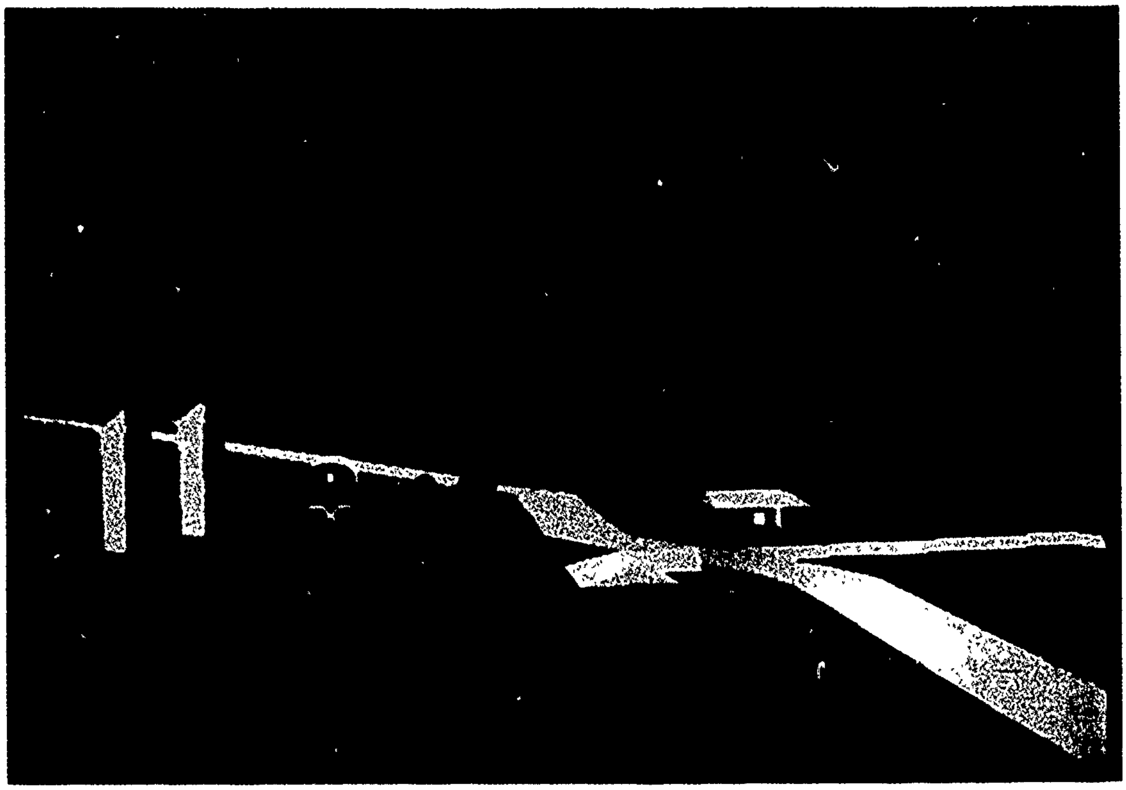


Photo 3. Group 1: Example of a low level generic environmental which requires 250 polygons to model the scene.

Photo 4. Group 1: Example of a low level generic environmental which requires 300 polygons to model the scene

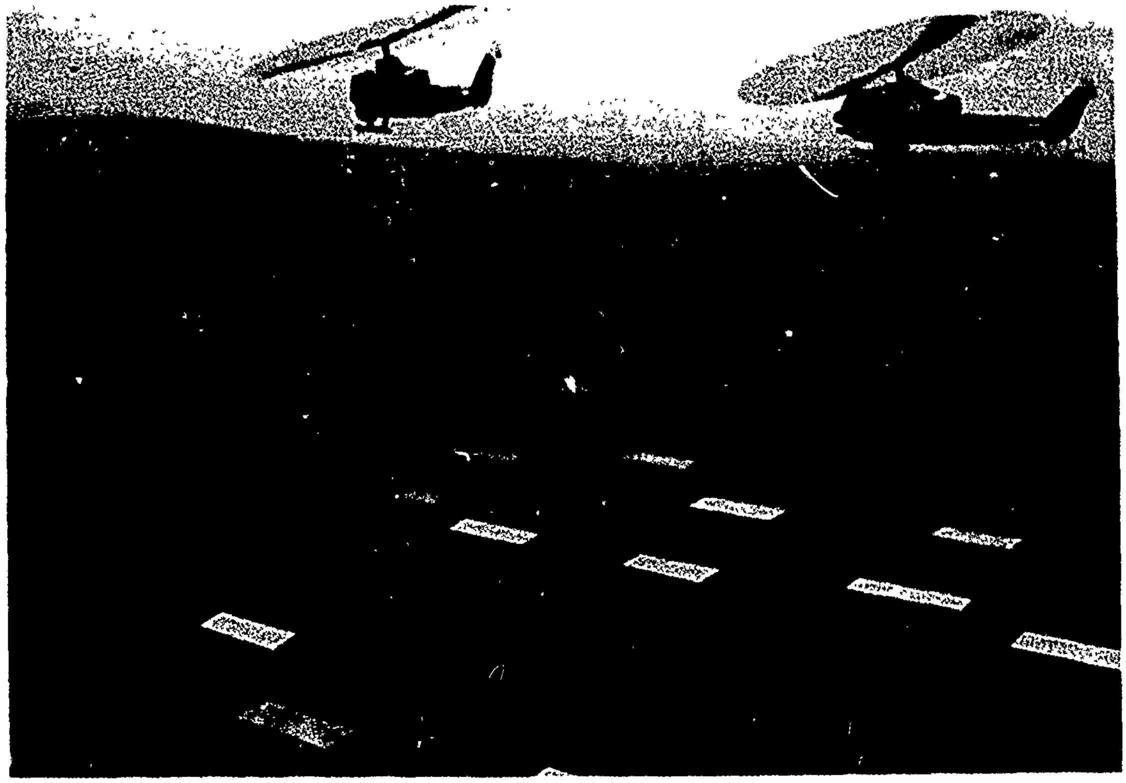


Photo 5. Group 2: Example of a medium level generic flight scene which requires 600 polygons to model the scene.

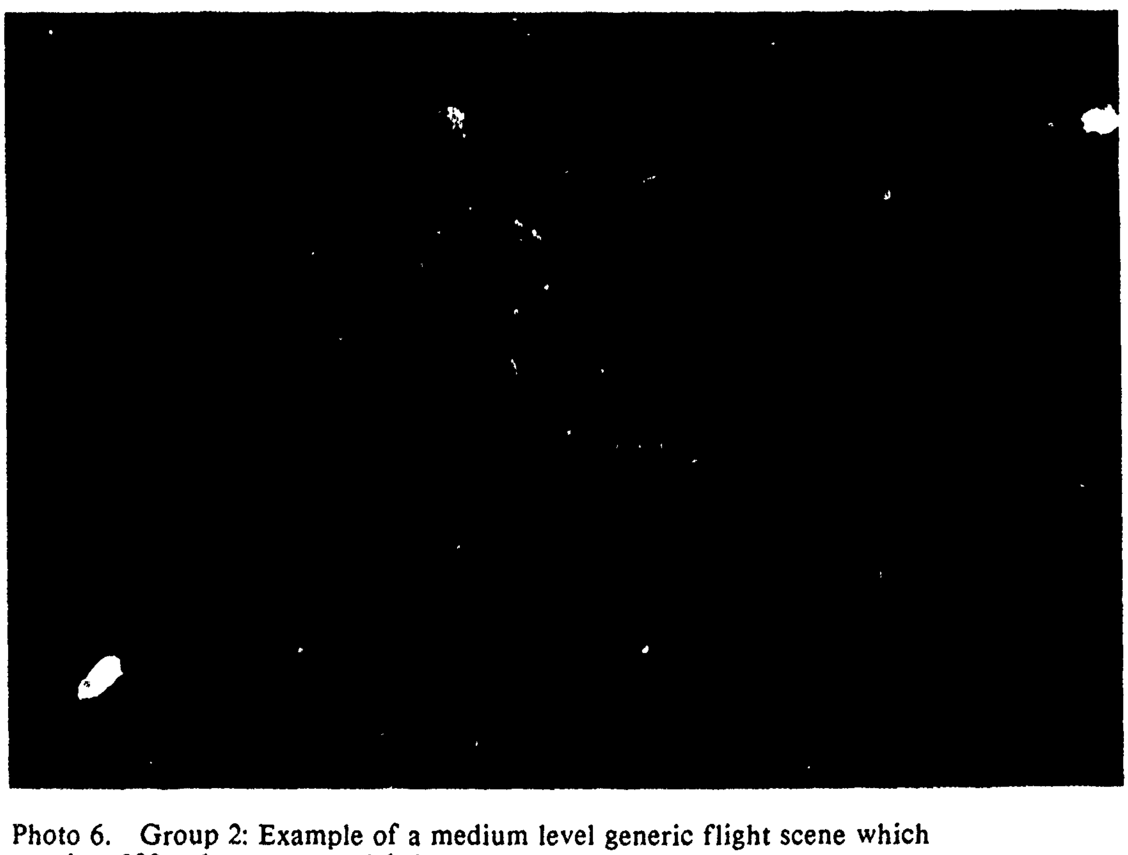


Photo 6. Group 2: Example of a medium level generic flight scene which requires 800 polygons to model the scene.

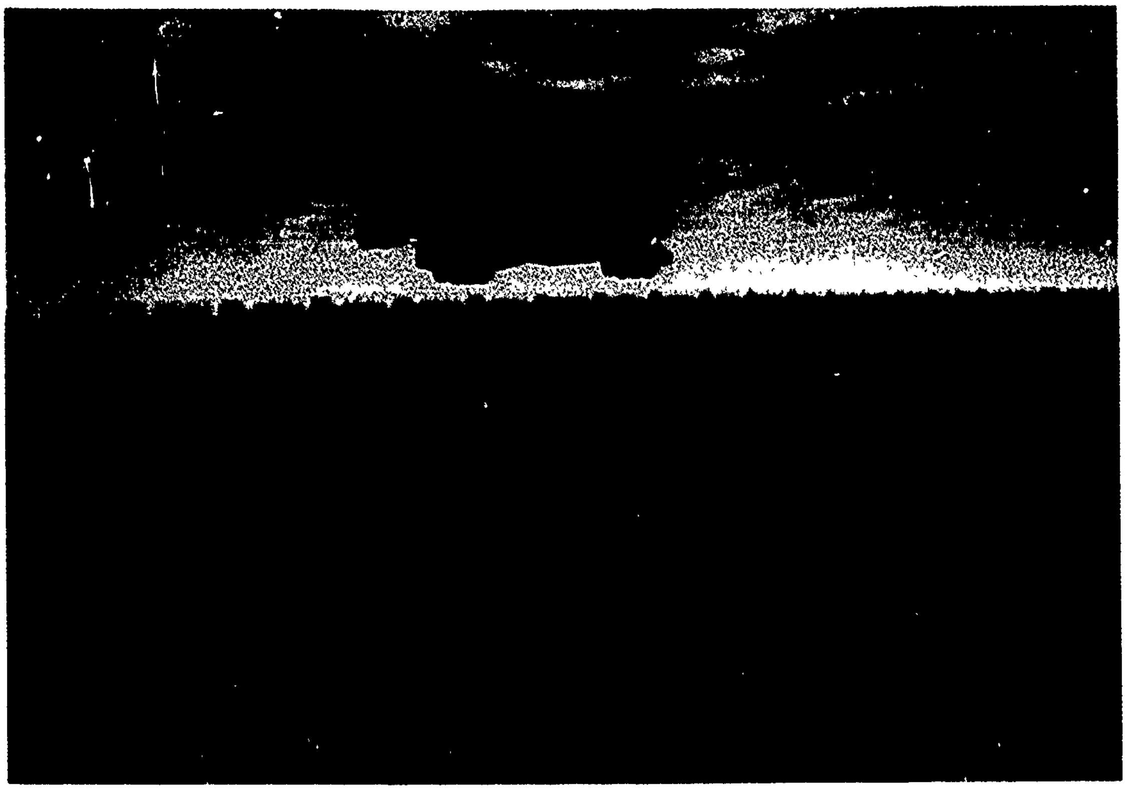


Photo 7. Group 2: Example of a medium level flight landing scene which requires 1000 polygons to model.

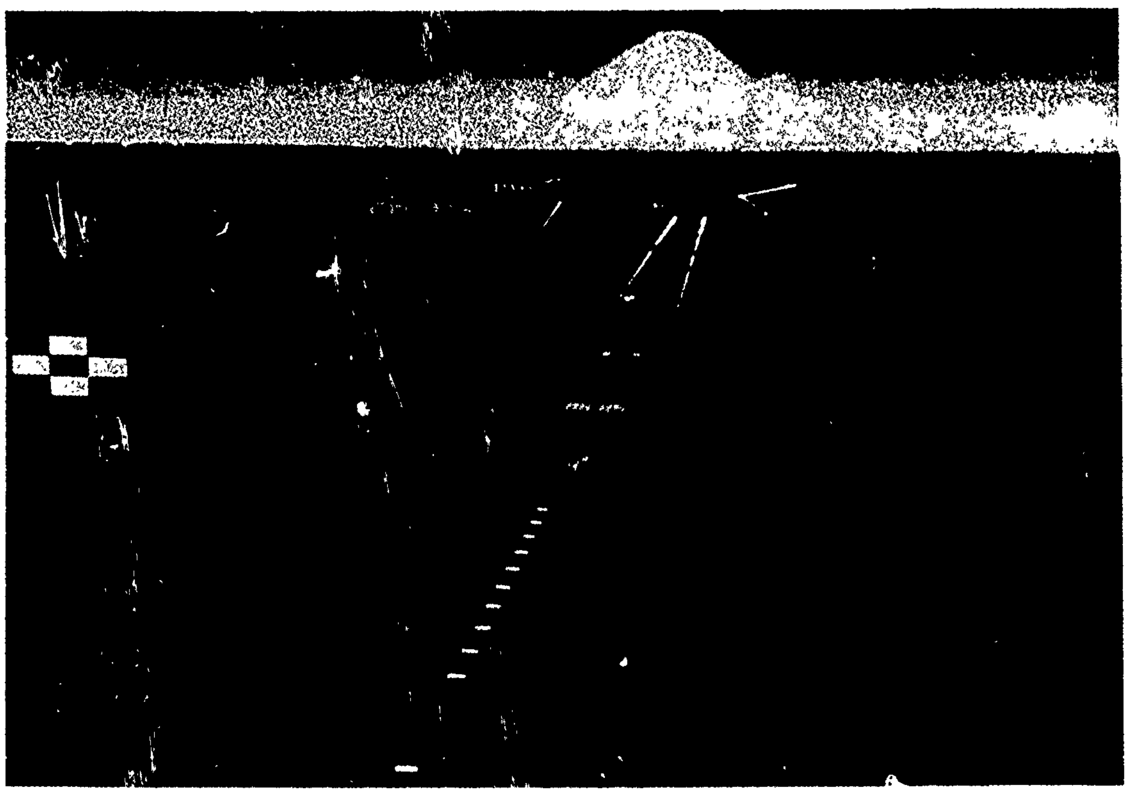


Photo 8. Group 2: Example of a medium level flight landing scene which requires 1000 polygons to model.

Photo 9. Group 3: Example of a high level flight landing scene which requires 1200 polygons to model.

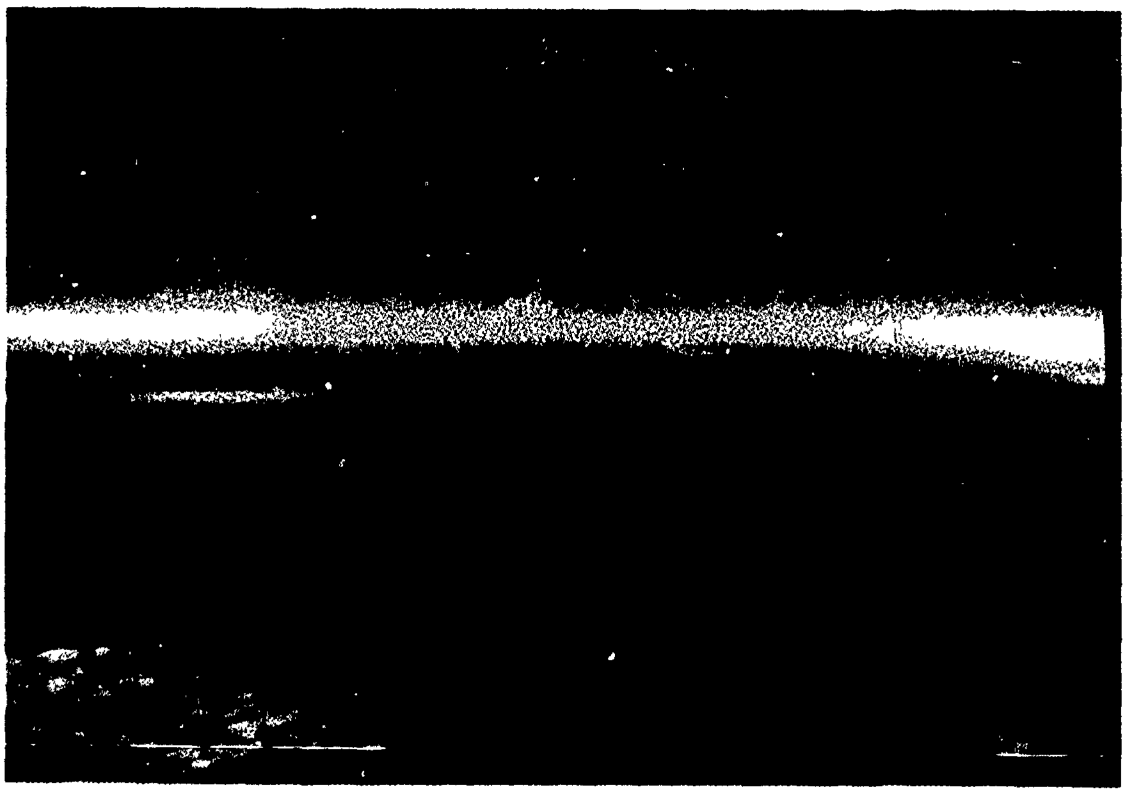


Photo 10: Group 3: Example of a high level flight landing scene which requires 1500 polygons to model.

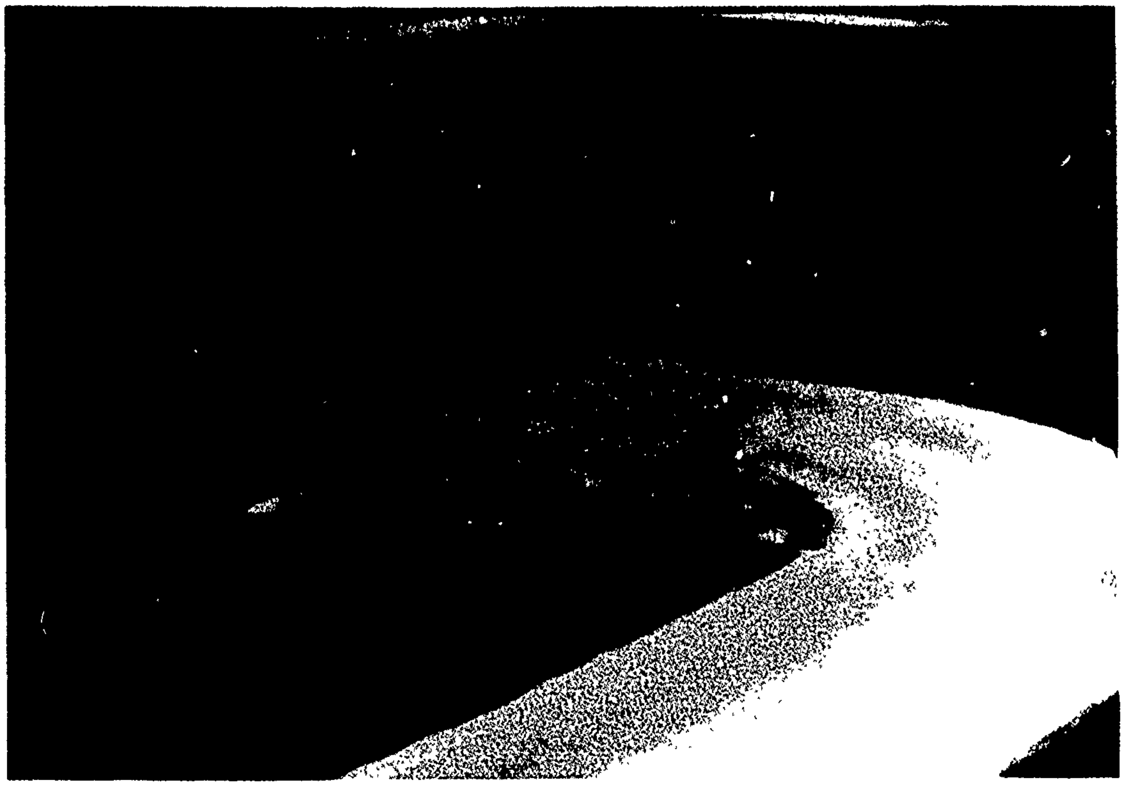


Photo 11. Group 3: Example of a high level ground scene which requires 1700 polygons to model.

Photo 12: Group 3: Example of a high level flight scene which requires 2500 polygons to model.

Photo 13. Group 4: Example of a very high level ground scene which requires 6000 polygons to model.

Photo 14. Group 4: Example of a very high level carrier landing scene which requires 8000 polygons to model.

Photo 15. Group 4: Example of a very high level environmental scene which requires over one million polygons to model.

Of the four groups of photographs found at the end of this section, which set most closely resembles the level of scene complexity and detail required by your application?

_______ Group 1 : 0 to 300 PP
_______ Group 2 : 500 to 1000 PP
_______ Group 3 : 1000 to 5000 PP
_______ Group 4 : Greater than 5000 PP

Polygons Processed

Experimental Expert System

An experimental expert system was developed to illustrate a delivery system for this taxonomy and eventually can be used to integrate a large quantity of collected information, primarily because of the complexity of the paper taxonomy and the frequent and complex branching required by the user in the paper taxonomy. The expert shell system LEVEL V was chosen over other shells because of the ease in which it may be implemented (See Appendix A for the Expert System Code).

Level V is an automated reasoning program that uses knowledge about a subject to arrive at a solution. The subject knowledge is stored and accessed from a database. It responds in a manner similar to that of an expert presented with the same problem. Expert knowledge typically flows from the rules of thumb established internally by the subject mater expert (SME). These rules and hunches represent informal knowledge as "heuristic."

An expert system usually contains three major parts: a knowledge base, inference engine, and user interface. The collection of knowledge is referred to as a knowledge base which controls inferencing. Traditional expert systems generally employ if-then rules to represent this information. The inference engine is the driver program for the expert system. Ideally, it is problem independent so that it does not vary from one knowledge base to another. The inference engine compares information supplied by the user with the knowledge contained in the knowledge base and deduces whatever conclusions may logically follow. The user interface links the inference engine to the external environment using standard programming techniques.

The essence of the experimental concept demonstration was to determine if an expert system is the best method for ease of use, for the consolidation and storage of data, and for ease of modification.

Taxonomic Transformations of Visual Media Selections into Display Specifications

Discussion

CONTRIBUTION

This work is the first study, to our knowledge, to develop a taxonomic design guide for users of visual media. The taxonomy serves to organize and define visual media choices and to facilitate system design. It specifies the minimum display requirements for visual characteristics of specific training devices, and for other applications as well.

The taxonomic structure bridges visual media and display specifications via psychophysical transformations. The taxonomy integrates (often invisibly to the user) sensory and perceptual correlates of image specifications, e.g., Boff, Kaufman, and Thomas (1986), and display design characteristics, e.g., Farrell and Booth (1984). Also included are portions of existing data bases based on human visual performance and visual training requirements, e.g., ANSI/HFS (1988) and Cohen, Gorog, and Carleson (1974). The structure has provisions for expansion as new findings, applications, and technologies arise.

Additionally, an electronic (expert system) provide a useful and "user friendly" delivery vehicle for seamlessly presenting essential information, yet hiding the complex transformations. The use of an expert system frees the user from searching through documentation in the attempt to locate diverse information. Yet, it allows rapid access to supporting explanatory material at appropriate times. In essence, the expert system organizes the material in a query structure that easily leads to a final listing of choice design parameters. This approach makes the task of selecting visual systems specifications a manageable one. The available documentation is assembled and organized, allowing direct access to data otherwise embedded in other findings.

USE

The taxonomy employs a user query system to determine specific scene content needs and relates those needs to specific display parameters. The query system guides the user through a series of questions to ascertain the most complex visual characteristics that will need to be displayed. Once the display requirements for the most complex scenes are determined, then images of lesser detail can easily be displayed. For example, if the scene only requires simple graphics presented statically, then the use of high fidelity graphics in motion is not needed. Most systems that have graphics capability have the capability of presenting text as well. Therefore, one set of higher level specifications also accounts for alphanumerics.

CAVEATS

This approach does not, nor can it, decide for the user, e.g., instructional designer, the minimum scene characteristics required to optimize training for a specific task. First, specific knowledge about the task is only available from the user through choices in the taxonomy. Second, specific principles for visual media selection are not available in the Instructional Technology (IT) literature, although general guidelines are given. Third, the determination of specific principles for selecting visual media to optimize training is beyond this project scope and time allotment. Thus, an Instructional System Design (ISD) process or other analysis is still required for each training application before the taxonomic structure can be applied. The taxonomic structure defined in this work complements but does not substitute for a sound instructional analysis of imaging requirements.

It must be emphasized that this taxonomy is an initial demonstration and not a product for distribution. It sets the foundation for further development. For example, since the taxonomy provides a new organization structure, past research does not easily fit into the format. Therefore, often only general trends were extracted from the literature. New research of some issues is needed to obtain more specific data for integration into existing structure.

FURTHER STUDY

Entering the taxonomy into the expert system will need more work. The concept demonstration in this study was only experimental. It did show the utility and advantage of building this taxonomy into an expert system shell. It also showed the ease of use and the insulation of the user from complex information structures. Others have extolled the virtues of using expert systems. In Feigenbaum's, et al., 1989, book The Rise of the Expert Company, they say expert system shells now are commonly and successfully used to provide a broad base of decision systems worldwide. After extensive study, they found more than 2,000 operational expert systems presently in existence. Expert systems have one significant advantage over more conventional software in that they have explanation capacity (Ragusa, Barron and Gibbons, 1989). This inherent feature is important to users as a verification of the decision process. New users, in particular, want explanations about the steps used by the system to reach conclusions.

More work is needed in the Instructional Technology area to provide a taxonomic structure for training choices. The instructional information and suggestions contained in the Results Section are only sufficient to serve as a preface to the taxonomy. Yet they are based on the extent of information given in authoritative texts written in the field of Instructional Technology by F. M. Dwyer, M. L. Fleming and W. H. Levie, R. M. Gagne and L. J. Briggs, P. O. Marsh, D. Meister, and R. Ritchey. As a first step, we have provided rules of thumb from Dwyer (1972) and presented structural guidelines from Marsh (1983) to guide the user into the taxonomy.

Finally, there were areas where information was either non-existent or not specific enough to be of help. These information gaps were identified in the taxonomy. Additional information is needed in the area of scene complexity, level of resolution required, and in the recommendation for field of view (FOV). For example, no specific FOV recommendations were found in the Instructional Technology literature. Guidelines simply stated not to choose display sizes too big or too small (e.g., Marsh, 1983). The FOV should be tied to specific training tasks and may be very different across applications. Thus, additional research needs to be conducted that relates FOV to task performance for making display size recommendations. Further research is also needed to address the issue of how much resolution (fidelity) and the levels of scene complexities that are sufficient for specific training tasks. An appropriate method is also needed for measuring and categorizing these two parameters.

CONCLUSION

This pioneering effort illustrates that design characteristics for a display system can be structured and tailored **by the user** to meet specific visual task requirements. This will help users, such as Instructional Technologists, to state clearly their requirements to design engineers. The taxonomy provides a structure to focus decisions about relevant characteristics of the image resulting in a description of the final delivery system. In this process, the structure filters image specifications through known human visual functions to take advantage of human capabilities and remain within human limitations. The taxonomic framework also can help identify further gaps in knowledge, that will stimulate new research. The framework allows and encourages the inclusion of new findings that will further improve effectiveness and usability.

The clear cut results of the experimental concept demonstration are that a software presentation of the taxonomy is accomplished with ease in an electronic expert system. It is recommended that the full paper taxonomy be converted to the expert system and that future expansions of the taxonomy be in software form; preferably added as modules and capable of being integrated with other Army presentation systems. Finally, the use of an expert system is the best vehicle to deliver a production form of the taxonomy.

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APPENDIX: Expert System Code

This sample knowledge base is constructed for concept demonstration of the paper taxonomy using LEVEL 5 (Information Builders, Inc, 1989), expert system shell. The knowledge base is transferred from the paper taxonomy according to the program code in this Appendix. .

A number of illustrations are designed using the program's graphic design tool for help information. Thus, user is eased into the problem domain and is helped to provide correct input into the system whenever system requests it. The system is entirely menu and function key driven.

To access this knowledge base, the user will need Level 5 ,professional version, by Information Builders, Inc.

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                          !
! Level 5 Knowledge Base Code                        !
!                                          !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
TITLE   Graphics
STRING aliasing
NUMERIC largest visual arc
AND  flicker ratio
AND  smallest visual arc
AND lum
AND moving flicker
!
!  Goal statements
!
1. final rule reached DISPLAY goal
  1.1 help
  1.2 no help

RULE start
IF CALL a:\demo.exe
THEN go
AND moving flicker :=0
AND retinal flicker :=0
AND size :=13
AND speed := 6
AND pixel x := 0
AND pixel y := 0
AND bit  := 0
AND memory :=0
AND n1 := 1024
AND n2 := 640
AND n3 := 512
AND n4 := 480
AND n5 := 256
AND n6 := 200

RULE text
IF Select Scene Characteristics IS  Alphanumeric
THEN text type
```

RULE graph
IF Select Scene Characteristics IS Two Dimensional Graphics
OR Select Scene Characteristics IS Three Dimensional Graphics
OR Select Scene Characteristics IS Three Dimensional Scenes
THEN graph type

RULE list of scene characteristics type
IF text type
OR graph type
THEN display type decision

RULE aliasing decision
IF go
AND Select Scene Characteristics IS Two Dimensional Graphics
OR Select Scene Characteristics IS Three Dimensional Graphics
OR Select Scene Characteristics IS Three Dimensional Scenes
AND DISPLAY aliasing help
AND PAINT a:\aliasing
AND Anti Aliasing IS YES
THEN anti aliasing is determined
AND anti_aliasing IS YES

RULE aliasing decision
IF go
AND Select Scene Characteristics IS Two Dimensional Graphics
OR Select Scene Characteristics IS Three Dimensional Graphics
OR Select Scene Characteristics IS Three Dimensional Scenes
AND Anti Aliasing IS NO
THEN anti aliasing is determined
AND anti_aliasing IS NO.

RULE aliasing decision
IF go
AND Select Scene Characteristics IS Alphanumeric
THEN anti aliasing is determined
AND anti_aliasing IS NO.

RULE decision of dynamic
IF anti aliasing is determined
AND Is there a need to show the object in motion ? IS Yes
AND CALL a:\moving.exe
THEN dynamic

RULE decision of static
IF anti aliasing is determined
AND Is there a need to show the object in motion ? IS No
THEN static

RULE movement ratio determine and flicker level 20
IF dynamic
AND Movement ratio is IS low: 0 ~ 20 degree per second
THEN movement ratio determine
AND moving flicker := 20

RULE movement ratio determine and flicker level 40
IF dynamic
AND Movement ratio is IS medium: 20 ~ 40 degree per second
THEN movement ratio determine
AND moving flicker := 40

RULE movement ratio determine and flicker level
IF dynamic
AND Movement ratio is IS high: 40 ~ 100 degree per second
THEN movement ratio determine
AND moving flicker := 50

RULE motion direction and flicker ratio level 30
IF movement ratio determine
AND Direction of motion is IS Horizontal
THEN motion
AND moving direction flicker := 30

RULE motion direction and flicker ratio level 60
IF movement ratio determine
AND Direction of motion is IS Vertical
THEN motion
AND moving direction flicker := 60

RULE motion direction and flicker ratio level 80
IF movement ratio determine
AND Direction of motion is IS Diagonal
OR Direction of motion is IS All of the above
THEN motion
AND moving direction flicker := 80

RULE retinal position reference and flicker ratio level 80
IF static
OR motion
AND retinal position is IS at the point of fixation
THEN retial position
AND retinal flicker := 80

RULE retinal position reference and flicker ratio level 60
IF static
OR motion
AND retinal position is IS less than 5 degrees from Fovea
THEN retial position
AND retinal flicker := 60

RULE retinal position reference and flicker ratio level 30
IF static
OR motion
AND retinal position is IS between 5 degrees and 30 degrees from Fovea
THEN retial position
AND retinal flicker := 30

RULE retinal position reference and flicker ratio level 20
IF static
OR motion
AND retinal position is IS larger than 30 degrees from Fovea
THEN retial position
AND retinal flicker := 20

RULE display duration
IF retial position
AND static
AND The minimum display duration IS YES
THEN minimum duration

RULE display duration
IF retial position
AND static
AND The minimum display duration IS NO
THEN determine duration

RULE if not minimum display duration
IF minimum duration
AND duration IS 80 ms
THEN duration value
AND duration flicker := 40

RULE duration
IF minimum duration
AND duration IS 50 ms
THEN duration value
AND duration flicker :- 20

RULE duration 80
IF minimum duration
AND duration IS 33 ms
THEN duration value
AND duration flicker := 30

RULE duration 50
IF minimum duration
AND duration IS 25 ms
THEN duration value
AND duration flicker := 40

RULE duration 10
IF minimum duration
AND duration IS 20 ms
THEN duration value
AND duration flicker := 50

RULE duration 17
IF minimum duration
AND duration IS 17 ms
THEN duration value
AND duration flicker := 50

```
RULE duration determine
IF determine duration
THEN  duration value
AND duration flicker := 30

RULE flicker rate determine for static
IF duration value
AND retial position
AND static
AND flicker level IS  critical
AND retinal flicker >= duration flicker
THEN static flicker is determined
AND flicker ratio := retinal flicker

RULE flicker rate determine for static
IF duration value
AND retial position
AND static
AND flicker level IS  critical
AND retinal flicker < duration flicker
THEN static flicker is determined
AND flicker ratio := duration flicker


RULE flicker rate determine for eliminate static
IF duration value
AND retial position
AND flicker level IS  eliminate
THEN static flicker is determined
AND flicker ratio := (retinal flicker + duration flicker)/2.0


RULE flicker rate determine for acceptable static
IF duration value
AND retial position
AND static
AND flicker level IS acceptable
AND retinal flicker <= duration flicker
THEN static flicker is determined
AND flicker ratio := retinal flicker


RULE flicker rate determine for acceptable static
IF duration value
AND retial position
AND static
AND flicker level IS acceptable
AND retinal flicker > duration flicker
THEN static flicker is determined
AND flicker ratio := duration flicker


RULE flicker ratio determine for critical dynamic
IF dynamic
AND retial position
AND flicker level IS critical
```

```
AND moving flicker >= moving direction flicker
THEN dynamic flicker ratio for critical
AND flicker ratio := moving flicker

RULE flicker ratio determine for critical dynamic
IF dynamic
AND retial position
AND flicker level IS critical
AND moving flicker < moving direction flicker
THEN dynamic flicker ratio for critical
AND flicker ratio := moving direction flicker

RULE decide flicker ratio critical
IF dynamic flicker ratio for critical
AND flicker ratio <= retinal flicker
THEN dynamic flicker is determined
AND flicker ratio := retinal flicker

RULE decide flicker ratio critical
IF dynamic flicker ratio for critical
AND flicker ratio > retinal flicker
THEN dynamic flicker is determined

RULE flicker ratio determine for acceptable dynamic
IF dynamic
AND retial position
AND flicker level IS acceptable
AND moving flicker <= moving direction flicker
THEN dynamic flicker ratio for acceptable
AND flicker ratio := moving flicker

RULE flicker ratio determine for acceptable dynamic
IF dynamic
AND retial position
AND flicker level IS acceptable
AND moving flicker > moving direction flicker
THEN dynamic flicker ratio for acceptable
AND flicker ratio := moving direction flicker

RULE decide flicker ratio acceptable
IF dynamic flicker ratio for acceptable
AND flicker ratio >= retinal flicker
THEN dynamic flicker is determined
AND flicker ratio := retinal flicker

RULE decide flicker ratio acceptable
IF dynamic flicker ratio for acceptable
AND flicker ratio < retinal flicker
THEN dynamic flicker is determined

RULE flicker ratio determine for eliminate dynamic
```

```
IF dynamic
AND retial position
AND flicker level IS eliminate
THEN dynamic flicker is determined
AND flicker ratio := (moving flicker + moving direction flicker+ retinal flicker)/3.0

RULE list of flicker
IF dynamic flicker is determined
OR static flicker is determined
THEN flicker ratio is determined

RULE Ambient light decision 1
IF flicker ratio is determined
AND Select Ambient light IS Theater lighting : ~ 0.7 to 0.34 candle per meter squared
THEN Al 1
AND flicker ratio := flicker ratio - 5

RULE Ambient light decision 2
IF flicker ratio is determined
AND Select Ambient light IS Low level office  : ~ 30  candle per meter squared
THEN Al 2
AND flicker ratio := flicker ratio

RULE Ambient light decision 3
IF flicker ratio is determined
AND Select Ambient light IS Routine office    : ~ 300 candle per meter squared
THEN Al 3
AND flicker ratio := flicker ratio + 5

RULE Ambient light decision 4
IF flicker ratio is determined
AND Select Ambient light IS Day light         : ~ 1,000 candle per meter squared
THEN Al 4
AND flicker ratio := flicker ratio + 10

RULE list ambient light
IF Al 1
OR Al 2
OR Al 3
OR Al 4
THEN Ambient light

RULE Field of view determine
IF Ambient light
AND FOV asking IS yes
OR FOV asking IS NO
THEN FOV asked

RULE known determine
```

```
IF FOV asked
AND FOV asking IS yes
THEN FOV known

RULE  unknown determine
IF FOV asked
AND FOV asking IS NO
THEN FOV unknown

RULE size for known 13
IF FOV known
AND select your preferred screen size IS 13 inch
THEN screen size is determined for FOV
AND size :=13

RULE size for known 17
IF FOV known
AND select your preferred screen size IS 17 inch
THEN screen size is determined for FOV
AND size :=17

RULE size for known 19
IF FOV known
AND select your preferred screen size IS 19 inch
THEN screen size is determined for FOV
AND size :=19

RULE size for known 21
IF FOV known
AND select your preferred screen size IS 21 inch
THEN screen size is determined for FOV
AND size :=21

RULE size for known 25
IF FOV known
AND select your preferred screen size IS 25 inch
THEN screen size is determined for FOV
AND size :=25

RULE size for known 36
IF FOV known
AND select your preferred screen size IS 2 by 3 ft
THEN screen size is determined for FOV
AND size := 36

RULE size for known  120
IF FOV known
AND select your preferred screen size IS 5 by 10 ft
THEN screen size is determined for FOV
AND size :=120


RULE number of viewers determine 1
IF FOV unknown
AND Number of user IS 1
THEN users
```

```
AND size := 13

RULE number of viewers determine 2
IF FOV unknown
AND Number of user IS 2
THEN users
AND size := 15

RULE number of viewers determine 3
IF FOV unknown
AND Number of user IS 3 to 8
THEN users
AND size := 16

RULE number of viewers determine 4
IF FOV unknown
AND Number of user IS 9 to 20
THEN users
AND size := 19

RULE number of viewers determine 5
IF FOV unknown
AND Number of user IS 20 to 100
THEN users
AND size := 25

RULE number of viewers determine 6
IF FOV unknown
AND Number of user IS larger than 100
THEN users
AND size := 40


RULE physical constraints determine
IF users
AND constraints asking IS YES
THEN asking constraint

RULE physical constraints determine
IF users
AND constraints asking IS NO
THEN asking non constraint


RULE selection constrains
IF users
AND constraints asking IS YES
AND select constraint IS  constraint 1
OR select constraint IS  constraint 2
OR select constraint IS constraint 3
OR select constraint IS constraint 4
THEN constraint value

!
!1) the nearest point for comfortable visual arc is classically !quoted as .4m(161 inches) for young people
```

!2) the range of viewing distance for best vision(for individual) !is 26 to 80 inches.

```
RULE observer distance read
IF screen size is determined for FOV
OR constraint value
OR asking non constraint
OR screen size is determined for FOV
AND Distance >= 0
THEN observer distance

RULE size determine for distance
IF observer distance
AND Distance > 0
AND Distance < 40
THEN determine screen size based on distance
AND dis size :=14

RULE size determine for distance 1
IF observer distance
AND Distance >= 40
AND Distance < 80
THEN determine screen size based on distance
AND dis size :=19

RULE size determine for distance 2
IF observer distance
AND Distance >= 80
THEN determine screen size based on distance
AND dis size :=25


RULE target size read
IF determine screen size based on distance
AND PAINT a:\retial
AND largest size >= 0
AND smallest size >= 0
THEN visual arc specification
AND largest visual arc := (57.3 * largest size)/Distance
AND smallest visual arc := (57.3 * smallest size * 60.0)/Distance

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc < 1.0
AND distance < 0.4
THEN pixel density decision by visual arc
AND pixel x := 1024
AND pixel y := 1024


RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 1.0
AND smallest visual arc < 5.0
AND distance < 0.4
THEN pixel density decision by visual arc
AND pixel x := n1
```

```
AND pixel y := n1

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 5.0
AND smallest visual arc < 10.0
AND distance < 0.4
THEN pixel density decision by visual arc
AND pixel x := n2
AND pixel y := n4

RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 10.0
AND smallest visual arc < 30.0
AND distance < 0.4
THEN pixel density decision by visual arc
AND pixel x := n3
AND pixel y := n3

RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 30.0
AND smallest visual arc < 60.0
AND distance < 0.4
THEN pixel density decision by visual arc
AND pixel x := n2
AND pixel y := n6

RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 60.0
AND smallest visual arc < 120.0
AND distance < 0.4
THEN pixel density decision by visual arc
AND pixel x := 256
AND pixel y := 256

RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 120.0
AND distance < 0.4
THEN pixel density decision by visual arc
AND pixel x := 320
AND pixel y := 200

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc < 1.0
AND distance >= 0.4
AND distance < 1.0
THEN pixel density decision by visual arc
AND pixel x := 1024
AND pixel y := 1024
```

```
RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 1.0
AND smallest visual arc < 5.0
AND distance >=0.4
AND distance < 1.0
THEN pixel density decision by visual arc
AND pixel x := 640
AND pixel y := 480

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 5.0
AND smallest visual arc < 10.0
AND distance >= 0.4
AND distance < 1.0
THEN pixel density decision by visual arc
AND pixel x :=  512
AND pixel y :=  512


RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 10.0
AND smallest visual arc < 30.0
AND distance >= 0.4
AND distance < 1.0
THEN pixel density decision by visual arc
AND pixel x := 640
AND pixel y := 200

RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 60
AND distance >= 0.4
AND distance < 1.0
THEN pixel density decision by visual arc
AND pixel x := 256
AND pixel y := 256


RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc < 1.0
AND distance >= 1.0
AND distance < 2.0
THEN pixel density decision by visual arc
AND pixel x :=  640
AND pixel y :=  480


RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 1.0
```

```
AND smallest visual arc < 5.0
AND distance >=1.0
AND distance < 2.0
THEN pixel density decision by visual arc
AND pixel x := 512
AND pixel y := 512

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 5.0
AND smallest visual arc < 10.0
AND distance >=1.0
AND distance < 2.0
THEN pixel density decision by visual arc
AND pixel x := 640
AND pixel y := 200

RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 10.0
AND smallest visual arc < 30.0
AND distance >=1.0
AND distance < 2.0
THEN pixel density decision by visual arc
AND pixel x := 256
AND pixel y := 256

RULE screen size decision based on visual arc 2
IF visual arc specification
AND smallest visual arc >= 30.0
AND distance >=1.0
AND distance < 2.0
THEN pixel density decision by visual arc
AND pixel x := 320
AND pixel y := 200

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc < 1.0
AND distance >= 2.0
AND distance < 5.0
THEN pixel density decision by visual arc
AND pixel x := 512
AND pixel y := 512

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 1.0
AND smallest visual arc < 5.0
AND distance >= 2.0
AND distance < 5.0
```

```
THEN pixel density decision by visual arc
AND pixel x := 640
AND pixel y := 200

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 5.0
AND smallest visual arc < 10.0
AND distance >= 2.0
AND distance < 5.0
THEN pixel density decision by visual arc
AND pixel x := 256
AND pixel y := 256

RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 10.0
AND distance >= 2.0
AND distance < 5.0
THEN pixel density decision by visual arc
AND pixel x := 256
AND pixel y := 256


RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc < 1.0
AND distance >= 5.0
AND distance < 10.0
THEN pixel density decision by visual arc
AND pixel x := 256
AND pixel y := 256


RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 1.0
AND smallest visual arc < 5.0
AND distance >= 5.0
AND distance < 10.0
THEN pixel density decision by visual arc
AND pixel x := 640
AND pixel y := 200


RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc >= 5.0
AND distance >= 5.0
AND distance < 10.0
THEN pixel density decision by visual arc
AND pixel x := 640
AND pixel y := 200
```

```
RULE screen size decision based on visual arc 1
IF visual arc specification
AND smallest visual arc > 0.0
AND distance >= 10
THEN pixel density decision by visual arc
AND pixel x := 256
AND pixel y := 256


RULE screen size decision based on visual arc 1
IF visual arc specification
AND FOV unknown
AND largest visual arc < 1.0
THEN screen size is determined for FOV unknown
AND size := 13

RULE screen size decision based on visual arc 2
IF visual arc specification
AND FOV unknown
AND largest visual arc >=1.0
AND largest visual arc < 10.0
THEN screen size is determined for FOV unknown
AND size := 15

RULE screen size decision based on visual arc 3
IF visual arc specification
AND FOV unknown
AND largest visual arc >= 10.0
AND largest visual arc < 30.0
THEN screen size is determined for FOV unknown
AND size := 17

RULE screen size decision based on visual arc 4
IF visual arc specification
AND FOV unknown
AND largest visual arc >= 30.0
THEN screen size is determined for FOV unknown
AND size  := 25


!Color

RULE color determine
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
AND Number of color IS 2
THEN number of color selection
AND color :=2
AND bit   :=1
AND lum := 200

RULE color determine 4
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
```

```
AND Number of color IS 4
THEN number of color selection
AND color :=4
AND bit   :=2
AND lum := 200

RULE color determine 8
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
AND Number of color IS 8
THEN number of color selection
AND color :=8
AND bit   :=3
AND lum := 100

RULE color determine 16
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
AND Number of color IS 16
THEN number of color selection
AND color :=16
AND bit   :=4
AND lum := 100

RULE color determine 32
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
AND Number of color IS 32
THEN number of color selection
AND color :=32
AND bit   :=5
AND lum := 100

RULE color determine 64
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
AND Number of color IS 64
THEN number of color selection
AND color :=64
AND bit   :=6
AND lum := 100

RULE color determine 128
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
AND Number of color IS 128
THEN number of color selection
AND color :=128
AND bit   :=7
AND lum := 100

RULE color determine
IF pixel density decision by visual arc
OR screen size is determined for FOV unknown
AND Number of color IS more than 128
THEN number of color selection
```

```
AND color :=256
AND bit  :=8
AND lum := 100


RULE two color consideration
IF number of color selection
AND Number of color IS 2
THEN monochrome
ELSE color screen

RULE type of monochrome graphics
IF monochrome
AND display type IS Light foreground and Dark background
OR  display type IS Dark foreground and light background
THEN positive or negative


RULE real time decision
IF positive or negative
OR color screen
AND graph type
AND NOT text type
AND ask real time \ yes
AND CALL a:\poly.exe
THEN real time

RULE no real time decision
IF positive or negative
OR color screen
AND graph type
AND NOT text type
OR ask real time \ no
AND CALL a:\poly.exe
THEN real time


RULE No complexity
IF positive or negative
OR color screen
AND text type
THEN no real time

RULE real time system
IF real time
AND scene complexity IS complexity low
THEN complexity is selected
AND cs := 1

RULE real time system
IF real time
AND scene complexity IS complexity med1
THEN complexity is selected
AND cs := 2
```

```
RULE real time system
IF real time
AND scene complexity IS complexity med2
THEN complexity is selected
AND cs := 3

RULE real time system
IF real time
AND scene complexity IS complexity high
THEN complexity is selected
AND cs := 4

RULE real time system for texture
IF real time
AND texture pattern IS pattern low
THEN Texture pattern is selected
AND ts := 1

RULE real time system for texture
IF real time
AND texture pattern IS pattern med1
THEN Texture pattern is selected
AND ts := 2

RULE real time system for texture
IF real time
AND texture pattern IS pattern med2
THEN Texture pattern is selected
AND ts := 3

RULE real time system for texture
IF real time
AND texture pattern IS pattern high
THEN Texture pattern is selected
AND ts := 4

RULE real time system for special effect
IF real time
AND special effect IS effect low
THEN special effect is selected
AND ss := 1

RULE real time system for special effect
IF real time
AND special effect IS effect med
THEN special effect is selected
AND ss := 2

RULE real time system for special effect
IF real time
AND special effect IS effect high
THEN special effect is selected
```

```
AND ss := 3

RULE determine the number of polygon
IF complexity is selected
AND Texture pattern is selected
AND special effect is selected
THEN find level of polygon
AND sum1 := cs + ts + ss

RULE level of polygon selection
IF find level of polygon
AND sum1 > 1
AND sum1 <= 5
THEN number of polygon level is determined
AND number of polygon IS low

RULE level of polygon selection
IF find level of polygon
AND sum1 >= 6
AND sum1 <= 7
THEN number of polygon level is determined
AND number of polygon IS medium 1
AND memory := memory + 1000


RULE level of polygon selection
IF find level of polygon
AND sum1 >= 8
AND sum1 <= 9
THEN number of polygon level is determined
AND number of polygon IS medium 2
AND memory := memory + 2000

RULE level of polygon selection
IF find level of polygon
AND sum1 >= 10
AND sum1 <= 11
THEN number of polygon level is determined
AND number of polygon IS high
AND memory := memory + 4000


RULE determine speed
IF number of polygon level is determined
AND image sequence IS one
AND user interaction IS non Interactive : passive viewing
AND script source IS stored script
THEN real time is determined
AND speed := 20


RULE determine speed
IF number of polygon level is determined
AND image sequence IS one
AND user interaction IS non Interactive : passive viewing
```

AND script source IS Generated script
THEN real time is determined
AND speed := 30

RULE determine speed
IF number of polygon level is determined
AND image sequence IS one
AND user interaction IS Interactive : behavior directed
AND script source IS stored script
THEN real time is determined
AND speed := 35

RULE determine speed
IF number of polygon level is determined
AND image sequence IS one
AND user interaction IS Interactive : behavior directed
AND script source IS Generated script
THEN real time is determined
AND speed := 40

RULE determine speed
IF number of polygon level is determined
AND image sequence IS two
AND user interaction IS non Interactive : passive viewing
AND script source IS stored script
THEN real time is determined
AND speed := 30

RULE determine speed
IF number of polygon level is determined
AND image sequence IS two
AND user interaction IS non Interactive : passive viewing
AND script source IS Generated script
THEN real time is determined
AND speed := 35

RULE determine speed
IF number of polygon level is determined
AND image sequence IS two
AND user interaction IS Interactive : behavior directed
AND script source IS stored script
THEN real time is determined
AND speed := 40

RULE determine speed
IF number of polygon level is determined
AND image sequence IS two
AND user interaction IS Interactive : behavior directed
AND script source IS Generated script

```
THEN real time is determined
AND speed := 50


RULE determine speed
IF number of polygon level is determined
AND image sequence IS three
AND user interaction IS non Interactive : passive viewing
AND script source IS stored script
THEN real time is determined
AND speed := 20


RULE determine speed
IF number of polygon level is determined
AND image sequence IS three
AND user interaction IS non Interactive : passive viewing
AND script source IS Generated script
THEN real time is determined
AND speed := 35


RULE determine speed
IF number of polygon level is determined
AND image sequence IS three
AND user interaction IS Interactive : behavior directed
AND script source IS stored script
THEN real time is determined
AND speed := 35


RULE determine speed
IF number of polygon level is determined
AND image sequence IS three
AND user interaction IS Interactive : behavior directed
AND script source IS Generated script
THEN real time is determined
AND speed := 40


RULE real time system determine
IF real time is determined
THEN real time system determined

! configuration the final specification

RULE determine memory size
IF real time system determined
OR no real time
THEN compute memory size
AND memory1 := pixel x * pixel y
AND memory1 := memory1 * bit / 8000
AND memory := memory + memory1

RULE determine luminance
```

```
IF compute memory size
AND Al 1
THEN lum for ambient light
AND lum := 10

RULE determine luminance 1
IF compute memory size
AND Al 2
THEN lum for ambient light
AND lum := 75

RULE determine luminance 2
IF compute memory size
AND Al 3
THEN lum for ambient light
AND lum := 100

RULE determine luminance 3
IF compute memory size
AND Al 4
THEN lum for ambient light
AND lum := 300

! final value of screen size
RULE no screen size condition
IF FOV known
AND lum for ambient light
THEN screen size is completed

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc < 5.0
AND Distance < 0.4
THEN screen size for FOV and arc
AND size :=9

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 5.0
AND largest visual arc < 10.0
AND Distance < 0.4
THEN screen size for FOV and arc
AND size :=13

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 10.0
AND largest visual arc < 20.0
AND Distance < 0.4
THEN screen size for FOV and arc
AND size :=17
```

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 20.0
AND largest visual arc < 50.0
AND Distance < 0.4
THEN screen size for FOV and arc
AND size :=25

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 50.0
AND Distance < 0.4
THEN screen size for FOV and arc
AND size :=48

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc < 5.0
AND Distance >= 0.4
AND Distance < 1.0
THEN screen size for FOV and arc
AND size :=13

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 5.0
AND largest visual arc < 10.0
AND Distance >= 0.4
AND Distance < 1.0
THEN screen size for FOV and arc
AND size :=17

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 10.0
AND largest visual arc < 20.0
AND Distance >= 0.4
AND Distance <1.0
THEN screen size for FOV and arc
AND size :=25

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 20.0
AND largest visual arc < 50.0

AND Distance >= 0.4
AND Distance <1
THEN screen size for FOV and arc
AND size :=46

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 50.0
AND Distance >= 0.4
AND Distance <1
THEN screen size for FOV and arc
AND size := 126

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc < 5.0
AND Distance >= 1.0
AND Distance < 2.0
THEN screen size for FOV and arc
AND size :=17

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 5.0
AND largest visual arc < 10.0
AND Distance >= 1.0
AND Distance < 2.0
THEN screen size for FOV and arc
AND size :=25

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 10.0
AND largest visual arc < 20.0
AND Distance >= 1.0
AND Distance < 2.0
THEN screen size for FOV and arc
AND size :=46

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 20.0
AND largest visual arc < 50.0
AND Distance >= 1.0
AND Distance < 2.0
THEN screen size for FOV and arc
AND size := 126

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 50.0
AND Distance >= 1.0
AND Distance < 2.0
THEN screen size for FOV and arc
AND size := 126

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc < 5.0
AND Distance >= 2
AND Distance < 5
THEN screen size for FOV and arc
AND size :=25

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 5.0
AND largest visual arc < 10.0
AND Distance >= 2
AND Distance < 5
THEN screen size for FOV and arc
AND size := 46

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 10.0
AND Distance >= 2
AND Distance < 5
THEN screen size for FOV and arc
AND size := 126

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc < 5.0
AND Distance >= 5
AND Distance < 10.0
THEN screen size for FOV and arc
AND size :=46

RULE final display size decision for visual arc and distance

```
IF FOV unknown
AND lum for ambient light
AND largest visual arc >= 5.0
AND Distance >= 5
AND Distance < 10.0
THEN screen size for FOV and arc
AND size :=126

RULE final display size decision for visual arc and distance
IF FOV unknown
AND lum for ambient light
AND largest visual arc > 0.0
AND Distance >= 10.0
THEN screen size for FOV and arc
AND size :=126


RULE priority of constraint
IF screen size for FOV and arc
AND constraints asking IS NO
THEN no constraints size

RULE priority of constraint
IF screen size for FOV and arc
AND constraints asking IS YES
AND select constraint IS constraint 1
THEN constraint screen size is determined
AND size := 5

RULE priority of constraint
IF screen size for FOV and arc
AND constraints asking IS YES
AND select constraint IS constraint 2
THEN constraint screen size is determined
AND size := 9


RULE priority of constraint
IF screen size for FOV and arc
AND constraints asking IS YES
AND select constraint IS constraint 3
THEN constraint screen size is determined
AND size := 15

RULE priority of constraint
IF screen size for FOV and arc
AND constraints asking IS YES
AND select constraint IS constraint 4
THEN constraint screen size is determined
AND size := 17


RULE final rule
IF screen size is completed
OR no constraints size
```

```
OR constraint screen size is determined
THEN final rule reached

RULE help
IF final rule reached
AND help asking IS pixel
AND PAINT a:\pixel
THEN help
ELSE no help


! Text statements


TEXT Select Scene Characteristics


   In your simulation, what media forms will have to be displayed?

         Note: 2-D and 3-D scenes are not completed

               Select alphanumeric or 3-D graphic option

TEXT Anti Aliasing

Do your scene quality needs require an anti aliasing feature?

TEXT movement ratio is

  What is ratio of movement across the screen ?
   Movement ratio is:

TEXT Direction of motion is

  Which direction of motion needs to be portrayed ?
   Direction of motion is:

TEXT retinal position is
  Where does the object fall on the observers retina ?
   Retinal position is:

TEXT The minimum display duration
  Is the minimum display duration less than 100 milliseconds(ms)?

TEXT duration
  What is the minimum display duration needed ?.

TEXT Select Ambient light
  What will be the predominant ambient lighting condition for viewing
  the display?

 TEXT number of user
   What is the expected number of simultaneous users of the display ?

   Number of users is:
```

TEXT select your preferred screen size
Please select a screen from the following lists of commercially available sizes:
Preferred screen size is :

TEXT critica'
1. Critical : flicker eliminated in most viewing conditions.
TEXT eliminate
2. Important : flicker will occur in some instances.
TEXT acceptable
3. Non-critical: display flicker is acceptable

TEXT select constraint
Please choose the category below that best describes the physical limitation:

TEXT Distance
What is the maximum distance of the viewer(s) to the display ?
(in meter)

TEXT flicker level
How critical is the removal of flicker from the presentation?
Removal of flicker from display environment is:

TEXT largest size

What is the size of the largest target you wish to have fully display. ?
(in meter)

It must be clear that the value we are asking for is not the actual size of the real world object but rather its ratio size as portrayed by the imaging system.

TEXT smallest size

What is the size of the smallest target you wish to have fully display. ?
(in meter)

It must be clear that the value we are asking for is not the actual size of the real world object but rather its ratio size as portrayed by the imaging system.

TEXT FOV asking

Do you have a predetermined FOV requirement ?

TEXT Number of color

How many color do you want displayed including all levels of shading and shadows ?.

EXPAND Number of color IS 2

This number is determined solely by the system user. A list of options will be given through a multiple choice selection table. A choice of two hues indicate a choice of a monochrome system. If shadows are to be used in the scene then the number of colors must be increased.

TEXT display type

You have chosen a monochrome system. Which of the following two options is preferred for the display presentation?

Positive (Light foreground on Dark background)
Negative (Dark foreground on Light background)

TEXT ask real time

Does the system require the images to be displayed in a real time manner ?.

TEXT scene complexity
Scene complexity is partially determined by the number of objects that need to be discernable at a given time. Which of the following levels of scenes object density most closely describes your requirement ?

TEXT complexity low
1. few objects : 0 - 4
TEXT complexity med1
2. Some object : 5 - 10
TEXT complexity med2
3. Many objects : 10 - 20
TEXT complexity high
4. Large number of objects > 20

TEXT Texture pattern

What is the texture pattern present on the most complex object that will be displayed ?

TEXT pattern low
1. Flat texture
TEXT pattern med1
2. Simple repeating patterns
TEXT pattern med2

3. Complex repeating patterns
TEXT pattern high
4. Complex randomized texture patterns

TEXT image sequence
How are the images brought to the screen ?

TEXT one
1: Scenes are stored entirely and then brought up on screen.
TEXT two
2: Scenes are generated
TEXT three
3: Hybrid of stored and generated scenes

TEXT special effect
Which level of special effects presented below best describes system requirements ?

TEXT effect low
1. Graphic Enhancement
TEXT effect med
2. Actors
TEXT effect high
3. Atmospherics

TEXT user interaction
What role does the user play in the sequencing of images ?

TEXT script source
How are the sequences of presented images developed ?

TEXT constraints asking
Does there exist any physical size constraints in the area the display will be placed in: i.e., limitation in available space, limiting the physical size of the display casing ?

TEXT constraint 1
4" x 3" x 5"
TEXT constraint 2
8" x 6" x 9"
TEXT constraint 3
19" x 12" x 15"
TEXT constraint 4
18" x 16" x 17"

TEXT help asking
Do you want to know about pixel ?

DISPLAY goal

Display size	[size(5,0)] inch
Luminance Range of display	[lum(5,0)] fL
Number of Colors Displayed	[color(5,0)]
Pixel Density of Display	[pixel x(5,0)] by [pixel y(5,0)]
Refresh rate of di lay	[flicker ratio(5,0)] Hz
Graphic Representation Memory	[memory(5,0)] K bytes
System Speed	[speed(5,0)] MHz
Anti aliasing	Annti_aliasing]
Number of polygons	Nnumber of polygon]

Viewing Distance

This is the point at which maximum viewing will occur. We assume that the designer has a predetermined viewing distance established for the system that the display will be viewed at. The viewing distance will be used in the calculation of visual angle display size and of the visual angle of a targets most critical detail.

DISPLAY aliasing help

Aliasing information
Aliasing occurs when graphic lines linking points in a scene do not make a smooth transition, due to representation schemes in the hardware. Anti-aliasing software corrects this problem using interpolation techniques.
See next graphic information

EXPAND motion

Object Motion
Two types of motion information, moving rate and direction, influence to an observer's perception of motion. The two information are important in determining system specification such as system speed and flicker rate.
See next graphic example

END